Seated Anthropometry During Pregnancy

Final Report

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16. Abstract

This project quantified the anthropometry and positioning of pregnant drivers in the automotive environment. Testing was conducted in an adjustable laboratory seating buck that could be configured to represent different vehicle-package geometries with various belt anchorage locations. Twenty-two pregnant subjects, divided into five stature groups, were measured in the seating buck at 3, 5, 7, and 9 months of gestation. Subjects were tested in four of eight different vehicle-package/belt-anchorage configurations at each test session, and were permitted to adjust their seat fore/aft position, seatback angle, and steering-wheel angle to achieve a comfortable driving posture. The anthropometry data collected on this small sample showed that the size and external contours of the pregnant abdomen are relatively independent of maternal stature. In general, fore/aft seat position, steering-wheel angle, and seatback angle remained about the same throughout pregnancy for subjects in all stature groups. Abdomen-to-wheel clearances decreased with gestational age and were smaller at all gestational ages for shorter subjects. The uterus lies completely below the steering-wheel rim until the 5th month of pregnancy, and that the top quarter of the uterus lies above the steering-wheel rim by the 9th month. Lap-belt angles (relative to horizontal) decreased with gestational age, and were smaller for shorter subjects who sat further forward relative to the fixed anchor points. Data on lap-belt placement relative to the pelvis and uterus indicate that the potential for lap-belt loading of the uterus in a frontal crash exists, even with the lap belt properly positioned across the anterior superior iliac spines (ASIS). The shoulder belt crossed the sternum higher and crossed the clavicle more inboard in the later months of pregnancy.

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EXECUTIVE SUMMARY

The main goal of this project was to quantify the anthropometry and positioning of pregnant women while seated as drivers in the automotive environment. The results provide contour data for developing the second-generation pregnant abdomen, and quantify anthropometry issues for vehicle interior and restraint designers.

Testing was conducted in an adjustable laboratory seating buck equipped with an interactive road-scene display. The buck can be configured to represent different vehicle-package geometries and includes adjustable lap- and shoulder-belt anchorages. A sonic digitizer probe was used to collect three-dimensional data on body landmarks and abdomen surface contours, seat-belt centerline locations, and vehicle-interior targets. These coordinate data were used to establish the subject's posture and selected seating position within the vehicle, and to quantify the positioning of restraint belts relative to the occupant and the pregnant abdomen.

Twenty-two subjects, divided into five stature groups, were measured in the seating buck at 3, 5, 7, and 9 months of gestation. The test matrix included two different seat heights, representing mid-size sedan and minivan/light truck package geometries. The matrix also included two fixed lap-belt anchor points, and two fixed shoulder-belt anchor points. Subjects were tested in four different vehicle-package/belt-anchorage configurations at each test session, and were permitted to adjust their seat fore/aft position, seatback angle, and steering-wheel angle to achieve a comfortable driving posture.

The mean statures of subjects in the five different groups are 1513, 1579, 1627, 1656, and 1708 mm, respectively. As expected, measurements of weight, abdomen depth, fundal height, abdomen circumference, hip breadth, and anterior superior iliac spine (ASIS) breadth increased for all subjects throughout the course of pregnancy. These measures also showed that the size and external contours of the pregnant abdomen are relatively independent of maternal stature. Since pregnant abdomen size depends largely on fetal size, which is independent of maternal stature, this result seems reasonable. However, this finding is in conflict with previous estimates of pregnant abdomen contours by Culver and Viano (1990), who used scaling techniques and the assumption that the size of the pregnant abdomen is proportional to maternal stature. Based on the finding that pregnant abdomen size and shape is relatively independent of maternal stature, the average contours of all subjects from the third test session were averaged together to provide the contour for the second-generation pregnant abdomen ATD.

An important objective of this project was to investigate changes in seated driving posture and position throughout pregnancy. In general, fore/aft seat position, steering-wheel angle, and seatback angle remained about the same throughout pregnancy for subjects in all stature groups. As expected, taller subjects positioned the seat more rearward than shorter subjects. The location of the pregnant abdomen relative to the steering wheel was quantified by two measurements: abdomen-to-wheel clearance and uterus-to-wheel overlap. Abdomen-to-wheel clearance is the minimum distance between the bottom of the steering-wheel rim and the anterior external contour of the abdomen. Uterus-to-wheel overlap is the proportion of the uterus that lies above the steering-wheel rim. Abdomen-to-wheel clearance decreased with gestational age, with the average for all subjects changing from 139 mm at the first test session to 58 mm at the last test session. Clearances were smaller for shorter subjects at each gestational age, with mean clearances of 25 mm for Group 1 and 110 mm for Group 5 in the fourth test session. Measures of uterus-to-wheel overlap show that the uterus lies completely below the steering-wheel rim until the 5th month of pregnancy. By the 9th month, the top quarter of the uterus lies above the steering-wheel rim. The combination of decreasing abdomen-to-wheel clearance and increasing uterus-to-wheel overlap increases the potential for steering-wheel loading of the abdomen in a frontal crash for pregnant women in the final months of pregnancy.

Another objective of this project was to determine how belt-anchorage locations and changing abdomen size affect belt fit. A side-view angle of the lap belt relative to horizontal was calculated using the most forward point on the lap belt and a point on the belt near the anchor. Lap-belt angle decreased with gestational age, and was steeper for the more forward anchor position. The shallower lap-belt angle may explain why pregnant women often complain of difficulty keeping the lap belt properly positioned below their pregnant abdomen later in pregnancy. Based on tests with non-pregnant crash dummies, shallower lap-belt angles tend to increase the likelihood for submarining, so the decrease in lap-belt angle throughout pregnancy may increase the potential for lap-belt loading of the uterus later in pregnancy.

Data for lap-belt location relative to the subjects' pelvises show that the lap-belt centerline crosses within +/-20 mm of the ASIS landmarks in the vertical direction, indicating good placement for loading the bony pelvis rather than the soft abdominal tissues. However, the data also show that the lap belt is positioned at the front of the abdomen such that 50 to 80% of the uterus lies below the belt centerline after 20 weeks of pregnancy. Because the pregnant abdomen protrudes significantly in front of the pelvis in the later months of pregnancy, these results suggest that the potential for lap-belt loading of the uterus in a frontal crash exists, even if the lap belt remains properly positioned across the ASIS.

Side-view shoulder-belt angles were calculated from the D-ring to the point on the belt closest to the subject’s shoulder. The two different shoulder-belt anchorage positions showed distinctly different angles that were independent of gestational age and subject stature. From the front view, the shoulder belt crossed the sternum higher and crossed the clavicle more inboard in the later months of pregnancy.

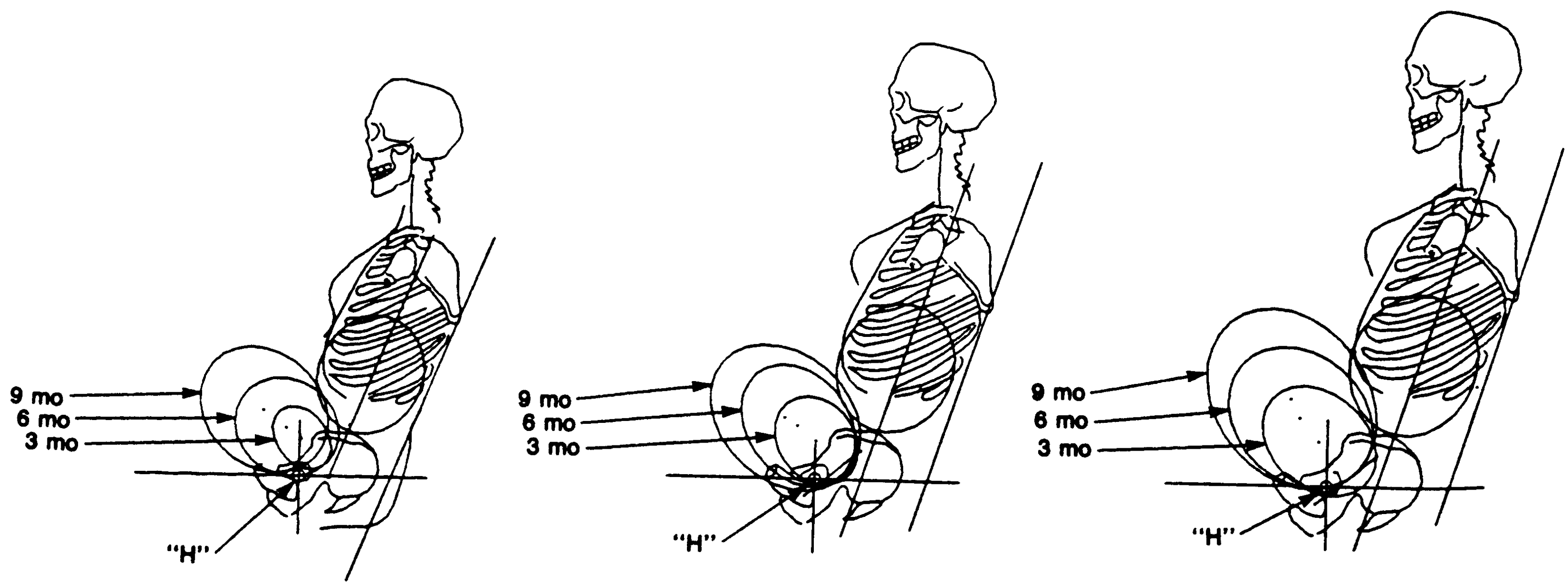
At the fourth test session, subjects were tested in an extra trial in which they were allowed to adjust the lap-belt anchorage location, the shoulder-belt anchorage location, and the pedal fore/aft location, in addition to the standard seat, seatback angle, and steering-wheel tilt adjustments. In these trials, subjects moved both the pedals and seat rearward, and they positioned the steering wheel to be more horizontal. This combination of adjustments increased the average abdomen-to-wheel clearance for all subjects by 24 mm compared to the configurations with fixed pedals. Subjects also tended to choose lower shoulder-belt anchor points and moved the lap-belt anchor point forward, thereby producing a steeper lap-belt angle.

1.0 INTRODUCTION

It has been estimated that between 1500 and 5000 fetal losses occur each year in the United States as a result of maternal involvement in automotive crashes (Pearlman 1997). This estimate was obtained by taking the number of births in the United States, multiplying by the estimated proportion of pregnant women involved in motor-vehicle trauma, and multiplying the result by the estimated frequency of fetal loss resulting from trauma. Additional uncounted adverse fetal outcomes undoubtedly occur as well, as many children grow up with disabilities as a result of injuries sustained in utero from motor-vehicle crashes (Klinich 1998, Baethmann et al. 1996). Also, the trauma of a motor-vehicle crash may lead to emergency delivery of a premature fetus and complications such as low birth weight and neonatal respiratory distress syndrome, which can lead to long-term negative consequences for the child (Pearlman 1997).

To provide a way to assess the potential for fetal injury and evaluate the effectiveness of potential countermeasures in restraint system or vehicle design, a first-generation pregnant abdomen was developed in the early 1990s for inclusion in the small-female Hybrid III ATD (Viano et al. 1996, Pearlman and Viano 1996). Accelerations of the simulated fetus in sled tests conducted with this modified crash dummy suggest that three-point belt systems offer the best protection to a fetus in a frontal crash. They also suggest that a deploying airbag may present a significant injury risk to the fetus of an out-of-position pregnant occupant positioned close to the airbag module. However, results of testing with the first-generation pregnant dummy are limited by the omission of injury criteria relating to placental abruption, which is considered the most important mechanism of fetal loss in motor-vehicle crashes (Pearlman 1997). In addition, the unrealistic abdomen size, shape, and stiffness may significantly affect the response and loading of the pregnant abdomen, pelvis, and simulated fetus from seatbelts, steering wheels, and deploying airbags.

A search of the literature revealed no quantitative data describing the anthropometry of pregnant women in the automotive environment. Medical studies of pregnant women tend to focus on weight gain and size of the uterus throughout gestation, which are of limited value to automotive safety researchers and engineers. Culver and Viano (1990) estimated the size and shape of the pregnant abdomens of small, average, and large women at several gestational ages in the automotive seated posture. Figure 1 shows approximations of the “pregnancy ellipses” that they generated. They determined the abdomen depth of 5th, 50th, and 95th percentile pregnant females at 3, 6, and 9 months of pregnancy by scaling British data based on differences in abdomen depth between U.S. and British females at three-months gestational age. The British data were derived by scaling data published on pregnant Japanese women, although details about the scaling were not described.



5th Percentile Female | 50th Percentile Female | 95th Percentile Female

Figure 1. Estimated profiles of small, average, and large women at various gestational ages (Culver and Viano 1990).

Prior to the current anthropometry study, a pilot study was conducted at the University of Michigan Transportation Research Institute to document the restraint use and positions of pregnant women in their own vehicles over the course of their pregnancies. A previously unpublished summary of the pilot study is provided in Appendix A. Of the eleven subjects tested, ten wore their lap and shoulder belts in the proper position throughout their pregnancy, with the lap belt low across the pelvis underneath the pregnant abdomen, and the shoulder belt over the sternum and alongside the pregnant abdomen. Subjects generally did not adjust their fore/aft seat position, seatback angle, or steering-wheel angle to compensate for their increasing abdomen depth, so the distance between the abdomen and the steering wheel decreased with increasing gestational age.

The current study was undertaken to obtain a more comprehensive and quantitative understanding of the changes in anthropometry of the pregnant occupant over the course of pregnancy, and the effect of these changes on the spatial relationships between the pregnant driver, the vehicle interior, and belt- and airbag-restraint systems. Data on the size and shape of the abdomen of the pregnant driver seated in a vehicle were also needed to define the anthropometry of abdomen of the second-generation pregnant crash dummy, which is being developed in Project D.7, “Development and Dynamic Testing of a Second-Generation Pregnant Abdomen.”

2.0 METHODS

The study of seated anthropometry during pregnancy focused on collection of anthropometric and body-posture data in four test sessions over the term of each subject's pregnancy. Test sessions were scheduled in the 3rd, 5th, 7th, and 9th months of each subject's pregnancy, corresponding to gestational ages of less than 15 weeks, 20-24 weeks, 28-32 weeks, and 36-40 weeks.

2.1 Subject Sampling [1]

Twenty-six pregnant subjects were recruited for the study by advertising in local newspapers and at obstetrician/gynecologist clinics. An effort was made to recruit subjects spanning a wide range of statures, but to include several short-statured women, since data were needed to design the abdomen for a small-female ATD. Investigators also tried to schedule each subject's first test session before she reached 14 weeks gestational age. However, a few subjects were scheduled for their first test session between 14 and 15-½ weeks if they reported minimal weight gain and body shape changes since becoming pregnant. A subject's anthropometry at this time in the pregnancy was considered close to her baseline pre-pregnancy measurements. Prior to participating in the study, each subject was asked to fill out a health questionnaire and to read and sign the consent form, provided in Appendix B.

Four subjects withdrew before completing the study for medical reasons, leaving twenty-two subjects for which a complete set of data was collected. Each qualified subject was placed into one of five stature groups based on the measure of stature without shoes taken in the first test session. Table 1 shows these stature groups and the distribution of the twenty-two subjects completing the study. As indicated, seven of the twenty-two subjects are under 1595 mm (5' 3").

Table 1
Subject Groups

Stature Group	Stature Range - mm	Mean Stature at First Test Session – mm (in)	Mean Mass at First Test Session – kg (lb)	Number of Subjects
01	< 1550	1513 (59.6)	61.0 (134)	3
02	1550-1595	1579 (62.2)	66.9 (147)	4
03	1596-1638	1627 (64.0)	64.0 (141)	5
04	1639-1681	1656 (65.2)	68.1 (150)	5
05	>1681	1708 (67.2)	67.6 (149)	5

[1] The rights, welfare, and informed consent of the volunteer subjects who participated in this study were observed under guidelines established by the U.S. Department of Health and Human Services on Protection of Human Subjects and accomplished under medical research design protocol standards approved by the Committee to Review Grants for Clinical Research and Investigation Involving Human Beings, Medical School, The University of Michigan.

2.2 Anthropometric Measurements

At the beginning of the first test session, several standard anthropometric measurements were taken on each subject to describe the subject's general body dimensions and proportions. These include several measurements to document the size of the pregnant abdomen. Figure 2 illustrates the standard seated measurements taken on each subject. Descriptions of all measurements are provided in Table 2. In the second through fourth test sessions, only dimensions that were expected to change with pregnancy were measured, as indicated in column 2 of Table 2. These include stature, weight, abdomen depth, abdomen circumference, hip breadth, anterior superior iliac spine (ASIS) breadth, buttock-knee length, and buttock-popliteal length. Seated fundal height was measured only in the last three sessions to provide a measure of uterine size, because the fundus is not reliably located early in pregnancy in a seated posture.

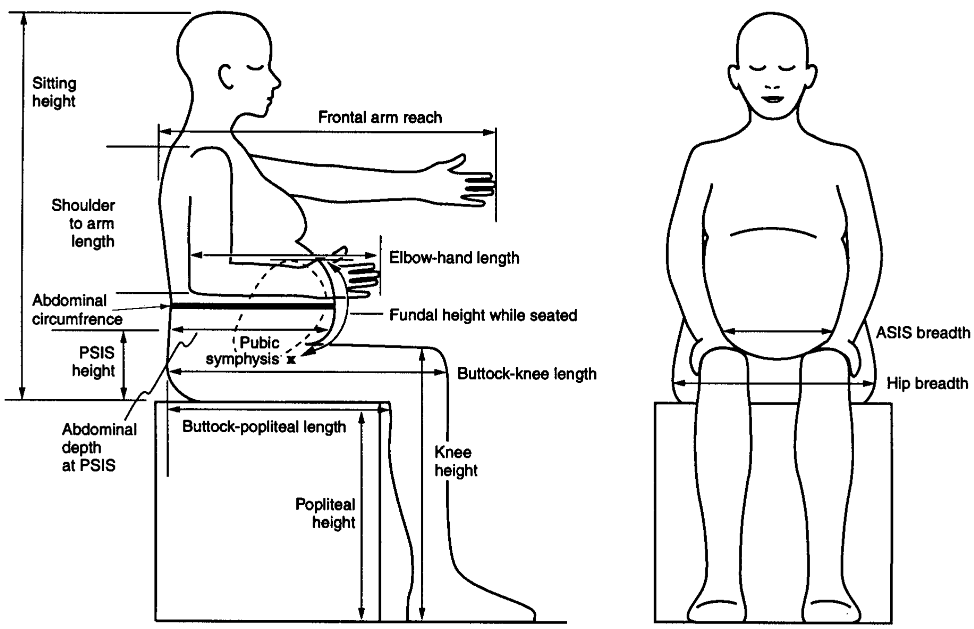


Figure 2. Illustration of standard seated anthropometry measurements.

Table 2
Anthropometric Dimensions

Dimension	Measured at all sessions	Definition
Abdomen circumference	x	With subject seated, measure the abdomen circumference at level of umbilicus.
Abdomen depth	x	With subject seated, measure the horizontal distance between most anterior point on subject's abdomen and most posterior point on subject's spine at the level of the PSIS.
Arm reach		With subject standing upright against a wall and extending arm horizontal, measure the distance from wall to tip of middle finger.
ASIS breadth	x	With subject seated, measure the distance between most anterior point of each palpated left and right anterior superior iliac spine (ASIS).
Buttock-knee length	x	With subject seated, measure the horizontal distance between most posterior point on buttocks and most anterior point of knee.
Buttock-popliteal length	x	With subject seated, measure the horizontal distance between most posterior point on buttocks and popliteal (junction of calf and thigh).
Forearm length		With subject positioning elbow at 90°, measure the horizontal distance from back of elbow to tip of middle finger.
Heel height	x	Height of subject's shoe at center of heel.
Hip breadth	x	With seated subject, measure the distance between the most lateral points on the hips.
Knee height		With subject seated, measure the distance between foot contact and most superior point of knee.
Popliteal height		With subject seated, measure the distance between foot contact and popliteal (junction of calf and thigh).
PSIS height		With subject seated, measure the vertical distance between seat surface and most posterior point of posterior superior iliac spine (PSIS).
Seated fundal height	x	With subject seated, measure the surface measurement of length between superior margin of the pubic symphysis and top of uterus.
Sitting height		With subject seated, measure the vertical distance between seat surface and top of head.
Stature	x	With subject standing, measure the vertical distance between standing surface and top of head.
Upper arm length		With subject positioning elbow at 90°, measure the vertical distance from back of elbow to top of shoulder.
Weight	x	With shoes removed, measure the subject's weight.

2.3 Test Facility

Testing was conducted in one of UMTRI's adjustable laboratory seating bucks shown in Figure 3. The seat, accelerator pedal, brake pedal, and instrument panel can be adjusted to orientations and positions representative of late-model production vehicles. For this study, the seating buck was equipped to include a three-point belt restraint with adjustable anchor points, a production steering wheel with tilt-wheel adjustment, and an interactive driving simulator display. The driving simulator display, shown in Figure 4, consists of a computer-generated road scene projected on a large screen television. Potentiometers connected to the accelerator pedal, brake pedal, and steering column allow the subject to perform simple driving tasks by controlling the speed and direction of the display.

Figure 3. Adjustable laboratory seating buck.

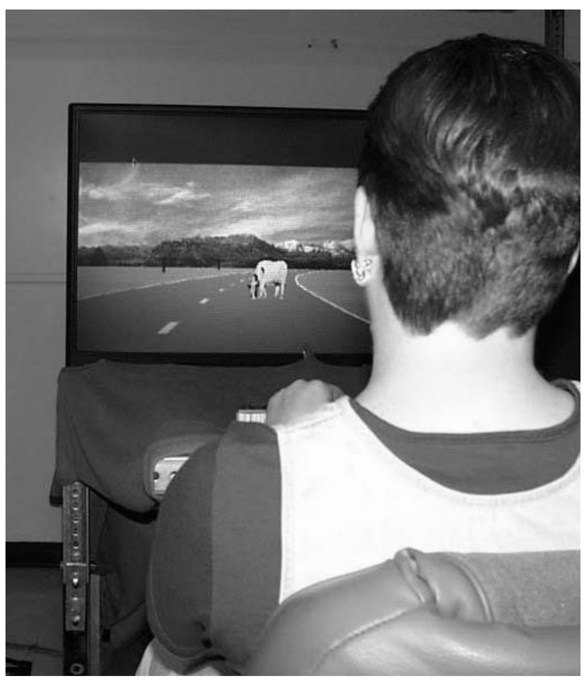


Figure 4. Driving simulator display.

Different belt angles were achieved by changing the locations of the belt anchor points using the adjustment mechanisms shown in Figure 5. Belt angles are defined as the angle of the belt relative to the horizontal, projected into the x-z or side-view plane, with the seat in the mean subject fore/aft position as determined using the UMTRI seating accommodation model described by Flannagan et al. (1998). As illustrated in Figure 6, the nominal lap-belt angle was defined as the angle relative to horizontal of a line connecting the H-point to the outboard belt anchor bolt. The nominal shoulder-belt angle, also shown in Figure 6, was defined by a line connecting the shoulder reference point, when viewed from the side, to the D-ring bolt. Lap-belt angles from 20° to 70° and shoulder-belt angles from 0° to 70° were possible with the fixtures shown in Figure 5.

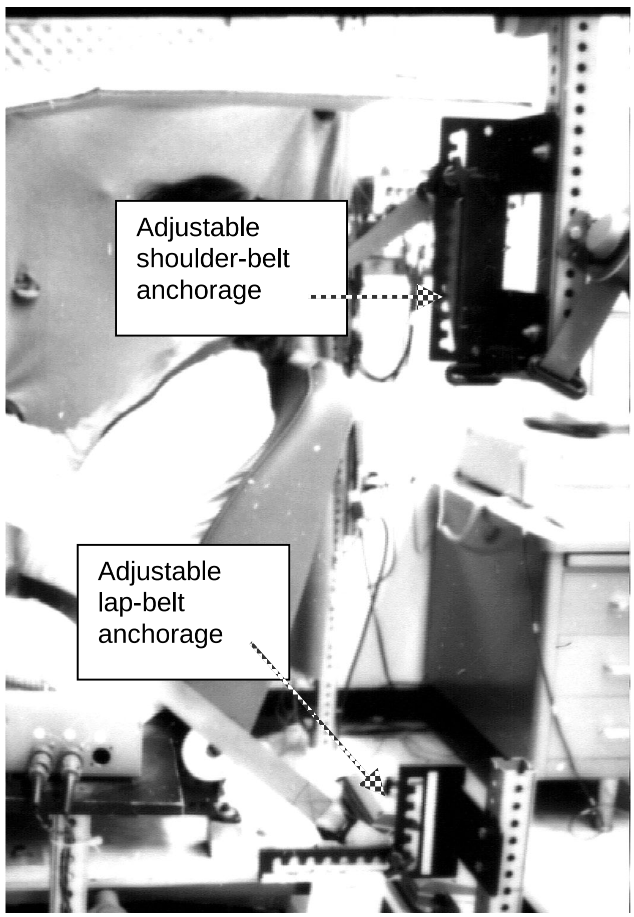


Figure 5. Side-view of test buck showing fixtures for adjusting seat-belt anchor points.

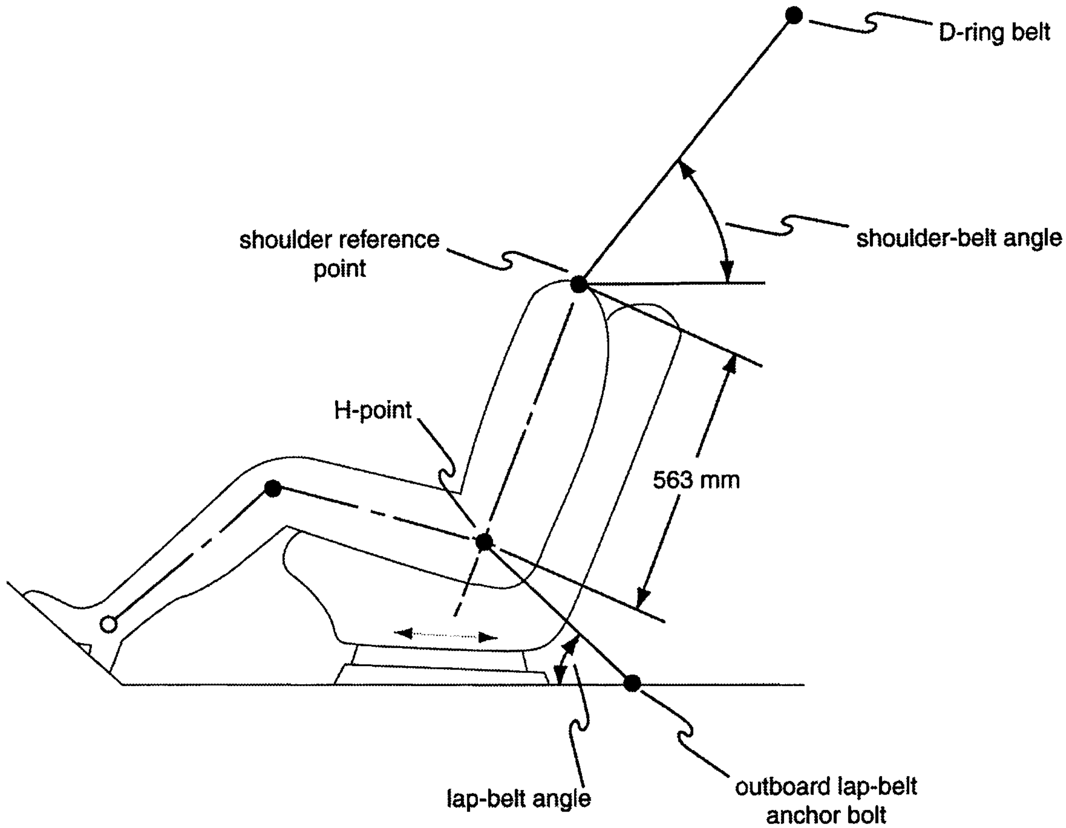


Figure 6. Definitions of nominal lap- and shoulder-belt angles
(seat at mean driver position per UMTRI model).

2.4 Sonic Digitizer

The seating buck is equipped with a sonic digitizer system manufactured by Science Accessories Corporation that was used to collect three-dimensional coordinates of spatial data. The system uses arrays of microphones to determine the locations of sonic emitters mounted to a measurement probe. Each emitter produces a sound pulse when an electric current arcs across a spark gap. A microprocessor converts the time it takes for the sound pulse to reach each of the four microphones in a fixed array into the distance from each microphone, thereby locating the emitter position relative to the microphone array.

During subject testing, human-body, buck-component, and belt-restraint targets and contours were digitized using a hand-held sonic probe. The probe consists of two sonic emitters fixed in the probe body, in line with, and at known distances, from the probe tip. With the tip of the probe on the desired target, a switch in the probe handle is used to trigger the two sonic emitters nearly simultaneously. The three-dimensional location of the probe tip is calculated trigonometrically using the locations of each of the probe emitters. Figure 7 illustrates the sonic probe being used to measure the abdomen contour.

Figure 7. Measurement of abdomen contour with sonic-digitizer probe.

Three arrays of microphones were used to collect data over the desired range of subject and buck targets. As pictured in Figure 8, two microphone arrays were located on the right side of the vehicle seat, while one array was positioned to the left of the seat. A calibration fixture (also shown in Figure 8) with a set of known target coordinates was periodically installed over the seat area and used to check the system calibration.

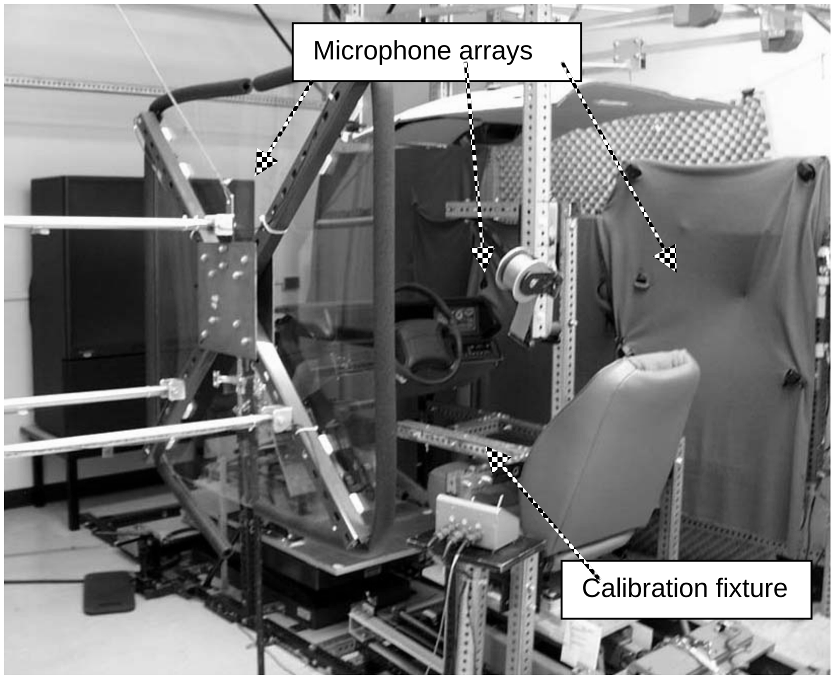


Figure 8. Seating buck with three microphone arrays and calibration fixture in place.

2.5 Test Conditions

Table 3 shows the matrix of eight different seating-buck configurations used in subject testing. This is a full-factorial matrix based on two levels of seat height, two lap-belt angles, and two shoulder-belt angles. Seat heights of 270 mm and 360 mm (typical of mid-sized sedan and van/light truck, respectively) were used, along with nominal lap-belt angles of 40° and 60° and shoulder-belt angles of 20° and 60°. Because of the need to limit each measurement session to about 1½ hours, each subject was tested in four of the eight configurations using a fractional factorial design, as indicated by the A and B subject sets in the last column of Table 3. Each subject was tested in the same four test configurations in each of four test sessions throughout her pregnancy.

Table 3
Test Matrix for Seated Anthropometry of Pregnant Women

Test Configuration	Seat Height -mm	Shoulder-Belt Angle -deg	Lap-Belt Angle –deg	Subject Set
C1	270	20	40	A
C2	270	20	60	B
C3	270	60	40	A
C4	270	60	60	B
C5	360	20	40	B
C6	360	20	60	A
C7	360	60	40	B
C8	360	60	60	A

During the last test session, the subject was also tested in a fifth "subject-selected" configuration. In addition to the regular adjustments of steering-wheel tilt angle, seat fore/aft position, and seatback angle, each subject was allowed to choose shoulder belt and lap-belt anchor points and a pedal fore/aft position that provided a "most comfortable" seating configuration. The investigator conducting the test session moved the belt anchorages and pedal positions through a range and the subject selected her preferred positions. The "subject-selected" configuration was always conducted with the randomly selected seat height used in the fourth configuration of the session.

The body landmarks and contour targets digitized in the seating buck are summarized in Table 4. They are defined in Table C1 of Appendix C. Table 5 lists and defines measurements taken to quantify the seating-buck configuration and subject-selected positioning of seat and steering column.

Table 4
Body Landmarks and Contour Targets taken in Seating Buck

Acromion, left and right
Anterior superior iliac spine (ASIS) L & R
C7
Corner of eye
Fundus (top of uterus)
Glabella (above bridge of nose)
Greater tubercle of humerus
Heel contact with floor
Infraorbitale
Lateral aspect of uterus, L & R
Lateral femoral condyle
Lateral humeral epicondyle
Lateral maleolus
Lateral neck
Manubrium (top of sternum)
Menton (chin)
Midline1-8
Midshoulder
Neck/shoulder junction
Occipital protuberance (back of head)
Pelvic-thigh junction (actual)
Pelvic-thigh junction (surface)
Pubic symphysis (PS)
Sterno-clavicular junction
Styloid process (wrist)
Supra patella (top of knee)
Top head
Tragion (ear-to-head junction)
Transverse abdomen contour (8 points)
Umbilicus
Xiphoid (bottom of sternum)

Table 5
Seating-Buck Targets used to Specify Vehicle-Package Geometry and Subject-Selected Positions of Seat and Steering Wheel

Target	Definition
Heel platform	Point on heel platform to record floor height.
Seat cushion	Point on side of seat cushion near the front used to check cushion angle.
Seat pivot	Point at intersection of seat cushion and seat back to mark fore/aft location.
Top of seatback	Point on side of seatback near the top used to check seatback angle.
Shoulder-belt anchorage bolt	Point at center of bolt connecting shoulder-belt D-ring to simulated B-pillar.
Top of instrument panel	Marked point at top of instrument panel.
Top of steering-wheel rim	Marked point at top of steering wheel at center of rim width.
Center of steering wheel	Marked point at geometric center of top surface plane of the steering wheel.
Bottom of steering-wheel rim	Marked point at bottom of steering wheel at center of rim width
Lap-belt points 1–20	Up to 20 points on centerline of lap belt, spaced 50 mm apart from restraint buckle to outboard anchors.
Shoulder-belt points 1–20	Up to 20 points on centerline of shoulder belt, spaced 50 mm apart from restraint buckle to D-ring.

2.6 Subject Measurements in a Reference Hardseat and Standing Position

In addition to collecting data on each subject in the seating buck as described above, a set of baseline measurements was taken on each subject in the fourth test session. These measurements were taken with the subject seated in a reference hardseat and in a standing posture. The measured landmarks and surfaces are defined in Table C1 of Appendix C. Table 6 lists the measurements taken in the reference hardseat and in a standing posture. These measurements include digitization of the palpated spinal processes for use in estimating the posture of the subject's spine in the seating buck using procedures developed by Reed et al. (1999).

Table 6
Anthropometric Targets Digitized in Reference Hardseat and Standing Posture

Target	Hardseat	Standing
Abdomen surface	X	
Acromion, left and right	X	X
ASIS (L), ASIS(R)	X	X
C7	X	X
Corner of eye	X	X
Fundus	X	X
Glabella	X	X
Infraorbitale	X	X
Lateral aspect of uterus, L & R	X	X
Lateral femoral condyle	X	X
Lateral humeral epicondyle	X	X
Manubrium	X	X
Menton	X	X
Occipital protuberance	X	X
PSIS(L), PSIS(R)		X
Pubic symphysis (PS)	X	X
Styloid process	X	X
Supra patella	X	X
T4,T8,T12,L3,L5	X	X
Top head	X	X
Tragion	X	X
Umbilicus	X	X
Xiphoid	X	X

For one subject from each stature group, the hardseat and standing measurements were taken at all four sessions. This subset of subjects also had an “abdomen sweep” measured, where the complete surface contour of the abdomen was digitized at each test session. The investigator digitized up to 60 points on the subject’s abdomen in a roughly gridlike pattern to quantify the entire surface of the pregnant abdomen relative to other bony landmarks.

2.7 Test Protocol

Prior to each test session, the investigator adjusted the seating buck to baseline conditions for the first configuration that was randomly selected from the set of four conditions for the session. This included setting the seatback angle, seat fore/aft position, pedal height and distance to seating reference point (SgRP), instrument panel height, shoulder-belt anchorage location, outboard lap-belt anchorage location, and steering-wheel angle. Table 7 lists the initial positions to which these components were adjusted.

Table 7
Initial Seating-Buck Configurations

	Configurations 1, 2, 3, 4	Configurations 5, 6, 7, 8
H30 (mm)	270	360
H-point-to-ball-of-foot (BOF) (mm)	953	902
Wheel Center to BOF distance (mm)	550	500
Steering-wheel tilt angle (deg)	30	30
Seat-cushion angle (deg)*	14.5	14.5
Seatback angle relative to vertical (deg)*	24	21
Seat-track position (mm)**	138	146
Instrument panel height (mm)***	1106	1080
Heel platform X position (mm)***	199	271
Heel platform Z position (mm)***	378	294

*Based on angular scale attached to seating buck.
**Based on scale attached to seating buck positioned so rearmost track position reads 0.
***Relative to laboratory coordinate system.

After entering the seating buck, the subject was instructed to adjust the fore/aft seat position, seatback angle, and steering-wheel angle to achieve her preferred position and posture. The subject then performed simple driving tasks using the interactive driver simulator display, while making further adjustments in the seat position, seatback angle, and steering-wheel angle. The simulator was then paused, the subject was instructed in the proper position of a three-point belt for pregnant women, and was then instructed to connect and position the belt-restraint system. The simulator was restarted and the subject performed additional driving tasks while wearing the belt restraint, making adjustments to the seat and steering-wheel tilt as desired.

Once the subject had achieved her preferred adjustments of the seat position, seatback angle, and steering-wheel tilt angle with the belt restraint fastened, the driving simulator was paused again and the subject was instructed to maintain her driving posture while measurements were taken. The seat position was noted using a linear scale attached to the buck, the seatback angle was measured using a protractor fixed to the seat, and her leg and thigh angles were measured using an inclinometer. The sonic digitizer probe was then used to collect three-dimensional coordinates of palpated body landmarks, points along the abdomen contour, targets along the centerlines of the lap and shoulder belts, and targets attached to vehicle components.

After completion of these measurements, the subject answered several questions concerning her position and proximity to interior vehicle components and the fit of the belt restraints. The questionnaire is provided in Appendix D, along with a questionnaire regarding the subject's driving habits in her own vehicle that she completed at the end of each test session. The subject then stepped out of the test buck while it was adjusted to the next configuration. During the repositioning process, subjects were not allowed to view the test buck. Testing was repeated until the subject had been tested in all four configurations.

At the end of the fourth measurement session, subjects were also allowed to adjust the locations of the shoulder- and lap-belt anchor points and pedal fore/aft position, along with adjustments in the seat, seatback angle, and steering-wheel tilt. This was done only for the last configuration of the session, which varied between subjects. After making these additional adjustments, the body landmarks, body contours, and belt positions were digitized, and the subject answered the same questions regarding belt fit and positioning relative to vehicle components.

3.0 ANALYSES AND RESULTS

3.1 Anthropometric Data

Table E1 in Appendix E contains the anthropometric data measured at the first test session for all subjects. Histograms of the weight and stature measured for all subjects during their first test session are provided in Figures 9 and 10, with values for the 10^{th}, 50^{th}, and 90^{th} percentile U.S. female also indicated (Abraham 1979). Figure 11 shows a histogram of body mass index (BMI) based on the subject's self-reported pre-pregnancy weight and stature measured at the first session. Recent guidelines by the National Institutes of Health suggest that a BMI above 25 is considered overweight, indicating that six of the twenty-two subjects were overweight at the start of their pregnancies.

Figure 12 shows a plot of weight vs. stature from the initial session of all subjects. The graph illustrates a fairly wide range of subject weight in the different stature groups, and shows that some of the heavier subjects are in the shorter groups. The correlation factor between weight and stature is 0.032, much lower than that reported in the Hanes II study of 0.27 (Hanes 1974).

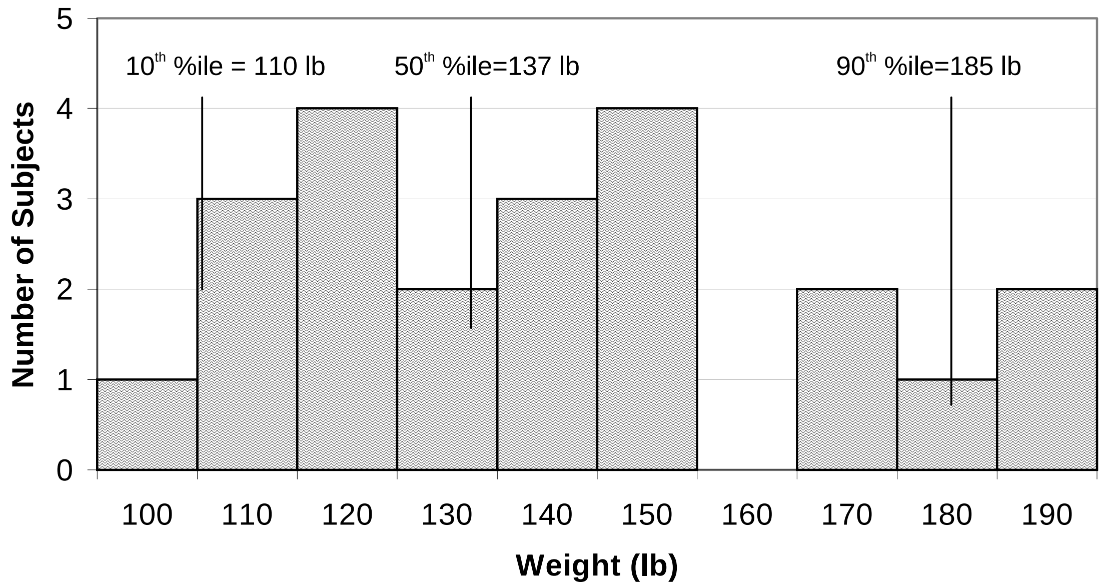


Figure 9. Frequency distribution of subject weight measured in first test session.

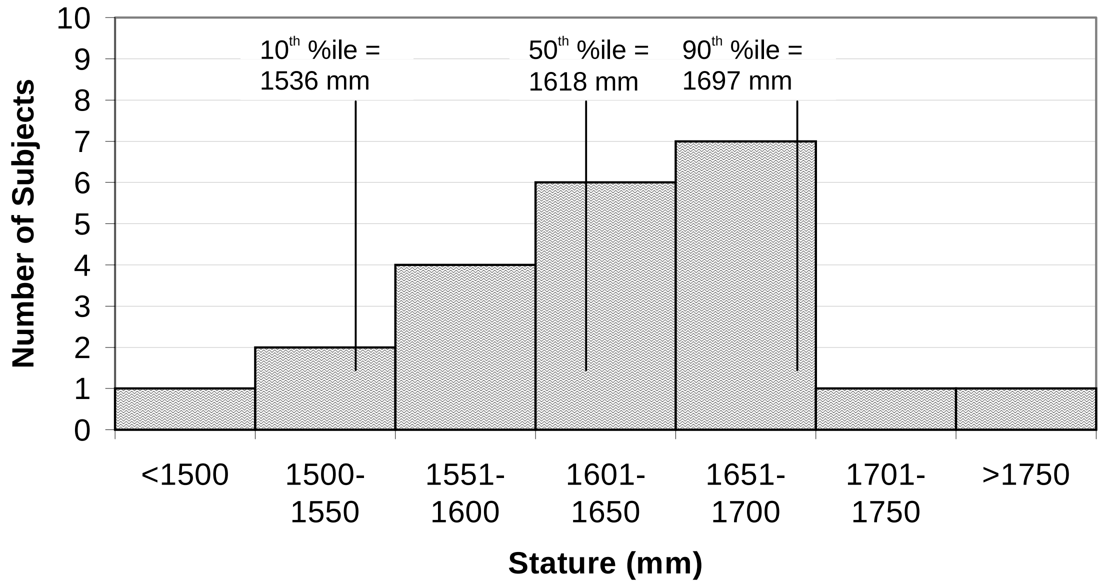


Figure 10. Frequency distribution of subject stature measured in the first test session.

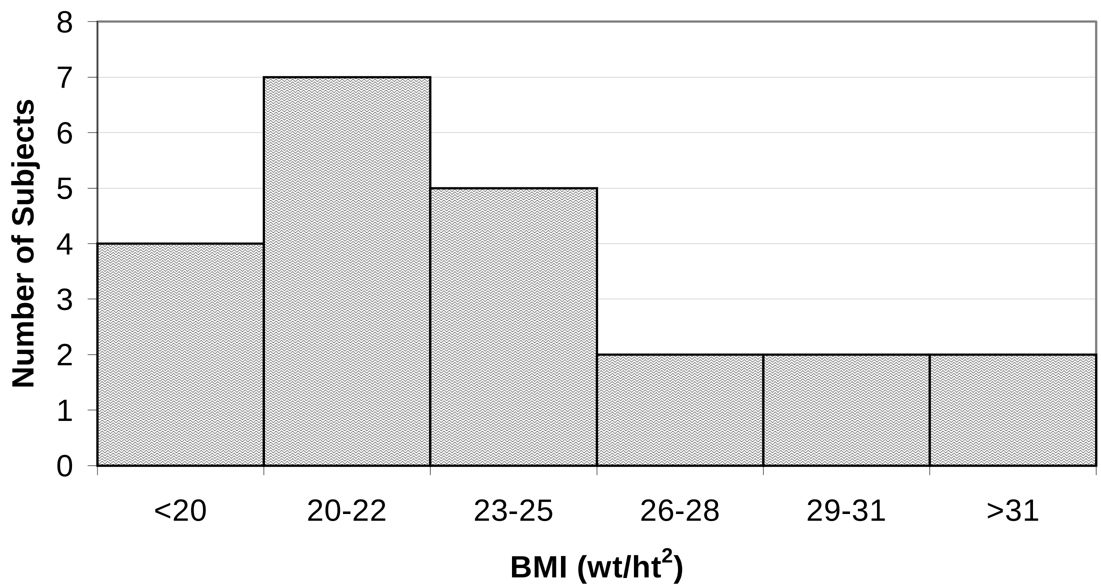


Figure 11. Frequency distribution of body mass index (BMI) measured in the first test session.

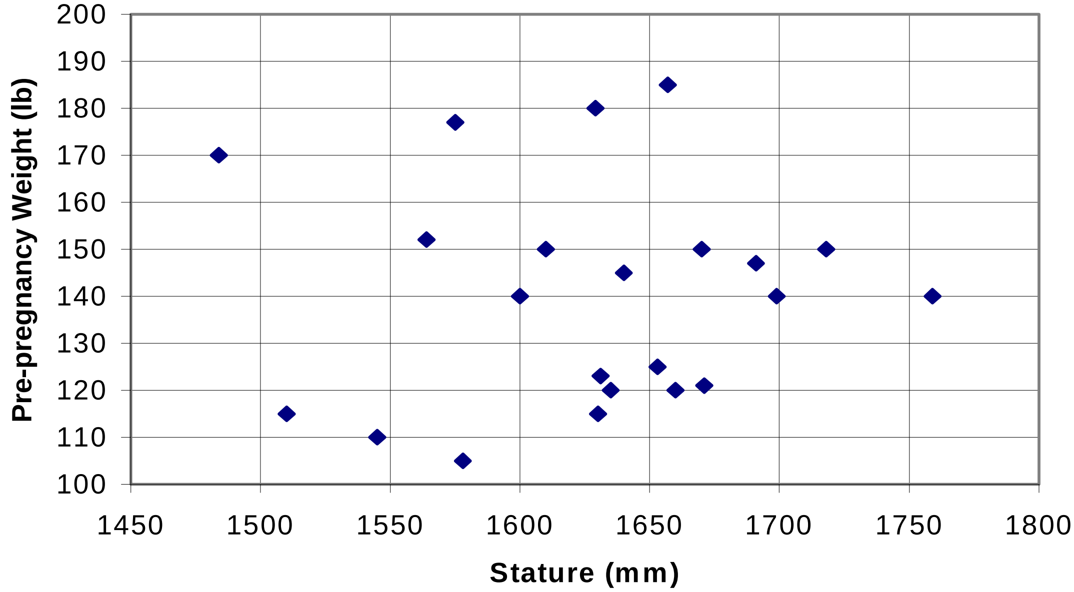


Figure 12. Subject pre-pregnancy weight vs. stature (r=0.032).

Data for the anthropometric variables measured in all four test sessions are provided in Table 2 of Appendix E. The anthropometric variables most associated with pregnancy, including weight, abdomen depth, abdomen circumference, and fundal height, all increased as expected with gestational age ($p<0.0001$ for all four variables). Plots of the changes in each of these variables as functions of gestational age are shown in Figures 13 through 16.

The average weight gain for all subjects (including one who reported gaining 25 pounds by the first session) are 5.0, 14.3, 23.2, and 36.8 for sessions one, two, three, and four, respectively. These gains are somewhat greater than values reported in an obstetrics text of 1.4, 8.8, 18.7, and 27.5 (Pritchard et al. 1985). Current recommended weight gain during pregnancy is 25 to 35 pounds, so many of these subjects are near the upper end of that range. The seated fundal height roughly corresponds with gestational age in weeks. In other words, a subject of 30 weeks' gestational age has a seated fundal height of 30 cm. This is the same relationship found with the prone fundal height, which is measured by physicians to check that the uterus is of proper size for the estimated gestational age.

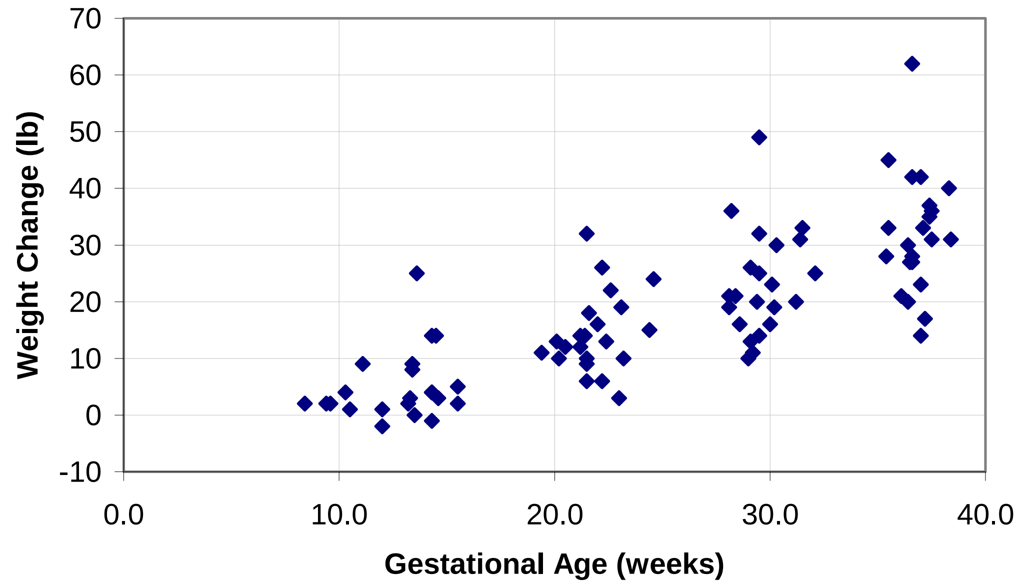


Figure 13. Weight gain as a function of gestational age relative to subjects' self-reported pre-pregnancy weight.

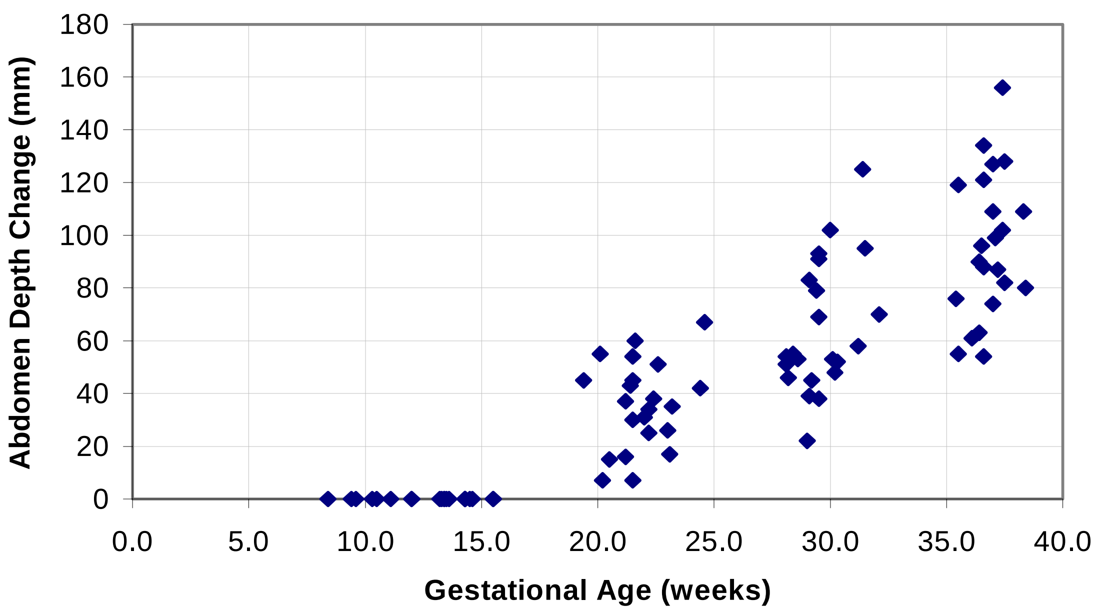


Figure 14. Change in abdomen depth from value measured at first test session as a function of gestational age.

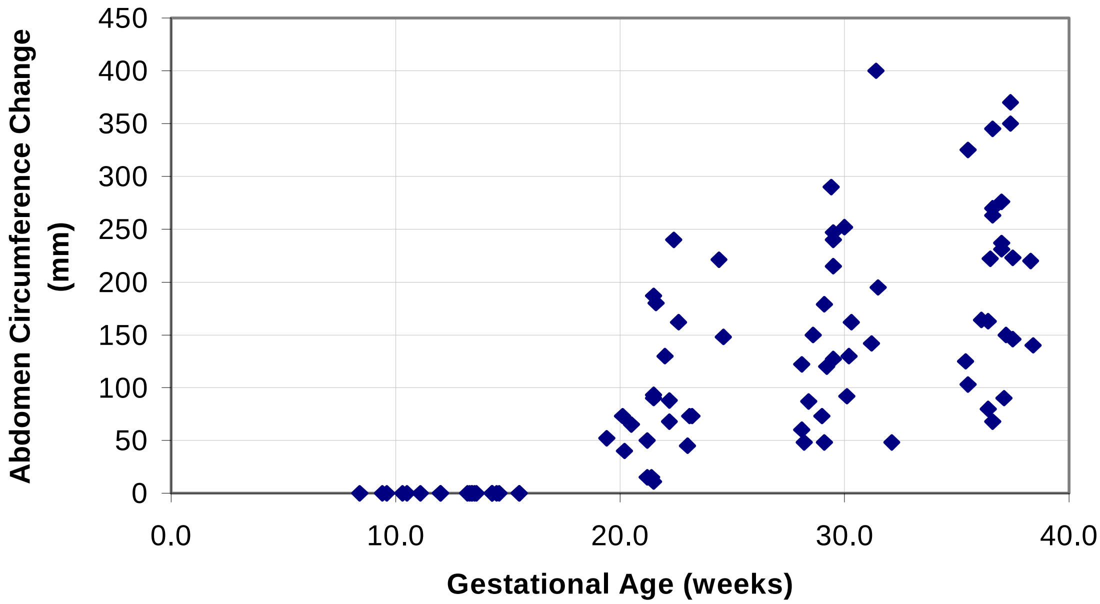


Figure 15. Change in abdomen circumference from value measured at first test session as a function of gestational age.

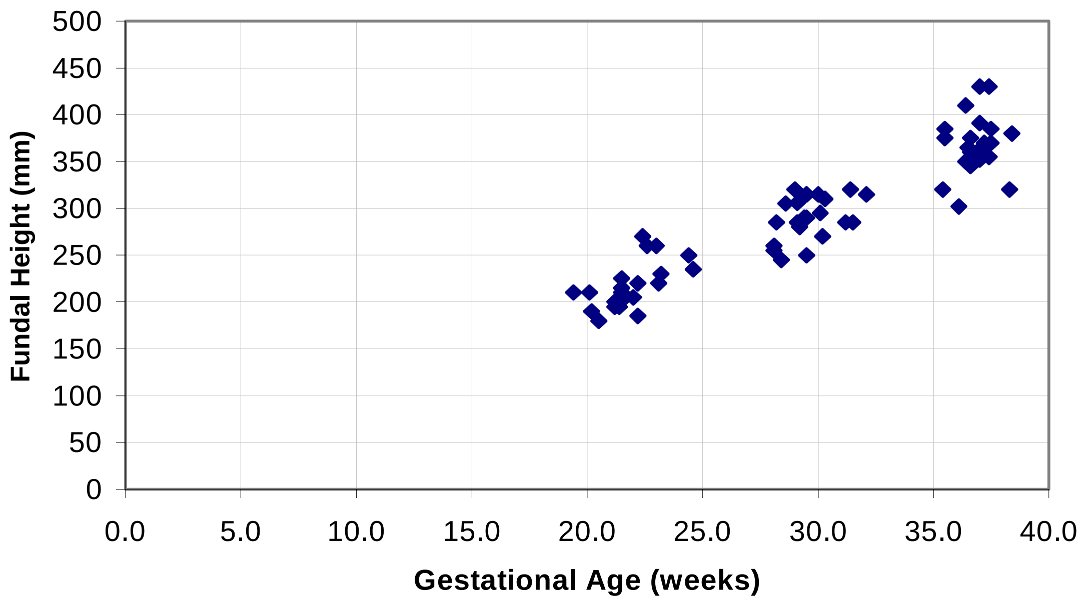


Figure 16. Fundal height as a function of gestational age.

The remaining anthropometric variables measured at each test session showed a slight tendency to increase with gestational age, as seen in Table E2 of Appendix E. These include BMI, buttock-knee length, buttock-popliteal length, hip breadth, and ASIS breadth. Only the increases in hip breadth (p=0.005) and ASIS breadth (p=0.010) were statistically significant over the course of pregnancy.

It had been hypothesized that stature might decrease with increasing gestational age because lumbar lordosis increases to balance the body's center of gravity shifting forward and downward. However, as shown in Figure 17, the change in stature relative to the first test session did not show any clear trend toward increasing or decreasing (p=0.632). Differences in stature measurements between sessions probably result from a combination of stature changes with time of day, variability in standing posture, and measurement error. The differences become somewhat more variable with gestational age, which may result from greater variability in standing posture resulting from increased lumbar lordosis.

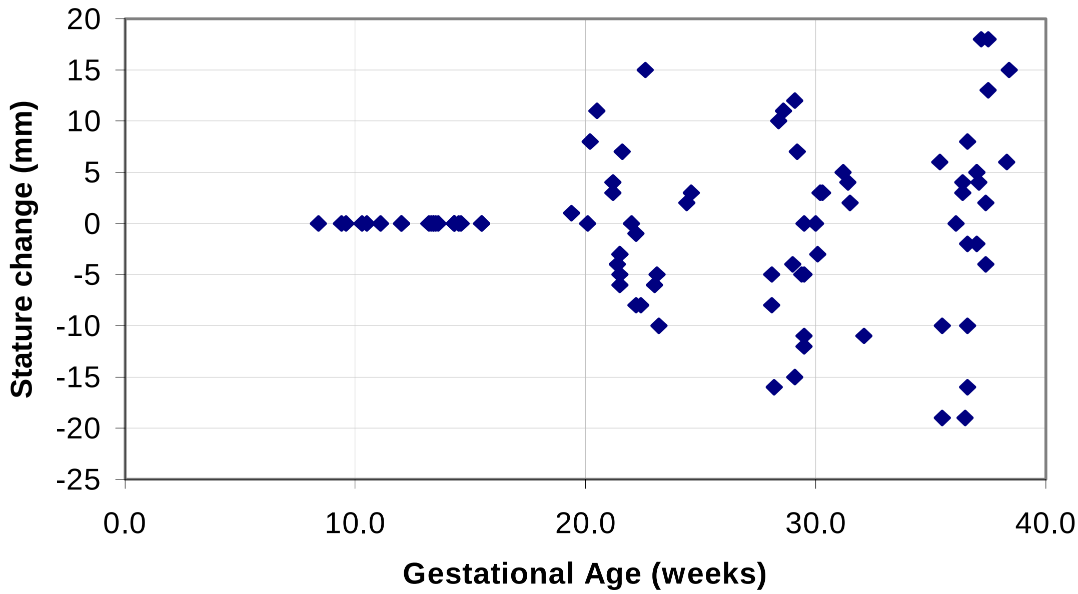


Figure 17. Change in subject stature relative to measurement in first session by gestational age.

The anthropometric variables measured in the first test session were examined for dependence on stature. Popliteal height, knee height, sitting height, forearm length, arm length, arm reach, PSIS height, buttock-to-knee length, and buttock-popliteal length show a weak relationship with subject stature. ASIS breadth, abdomen depth, abdomen circumference, and weight appear to be independent of subject stature. The lack of correlation between initial subject weight and stature is unexpected, as taller people usually weigh more. However, an effort was made to recruit a subject population that spanned a range of statures without consideration for weight and, as shown previously in Figure 12, pre-pregnancy weight is not a function of stature for the twenty-two subjects selected. The two subjects with the largest BMI are in stature Groups 1 and 2, and many of the Group 4 and 5 subjects had a low BMI, which partially explains this unexpected finding.

Figures 18 through 20 show scatter plots of abdomen depth, abdomen circumference, and fundal height versus subject stature from the four test sessions of each subject. As indicated, these measures show no correlation with subject stature throughout pregnancy. These three measures strongly depend on the size of the uterus, which depends on the size of the baby. Since most women deliver 6 to 9 pound babies regardless of maternal stature, this result is not unexpected. However, this result may also be influenced by the unusual lack of correlation between weight and stature found in this sample population.

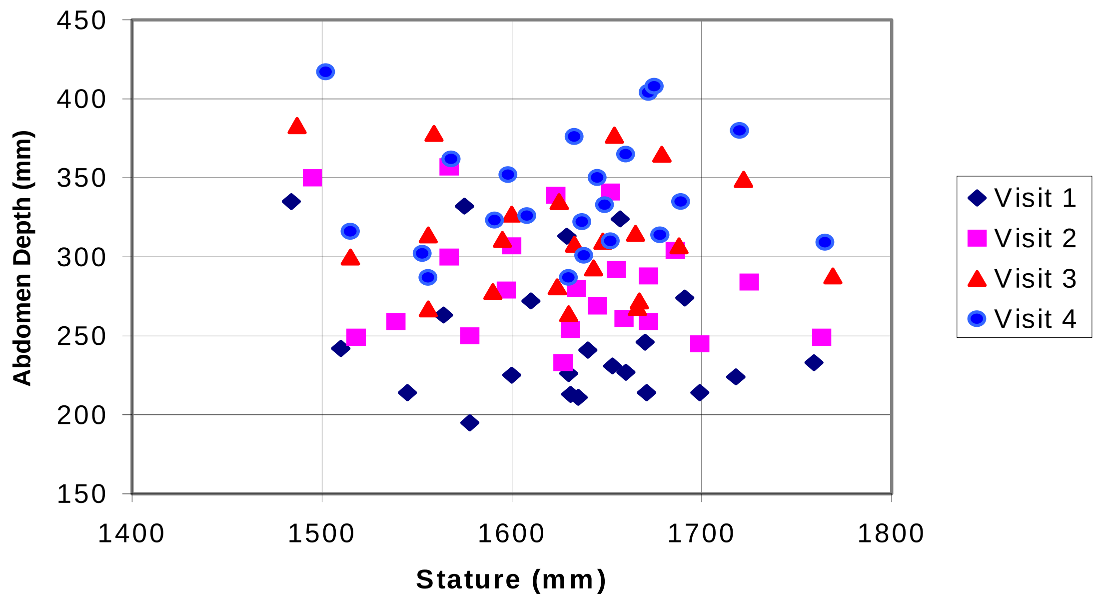


Figure 18. Abdomen depth vs. stature (r=0.126).

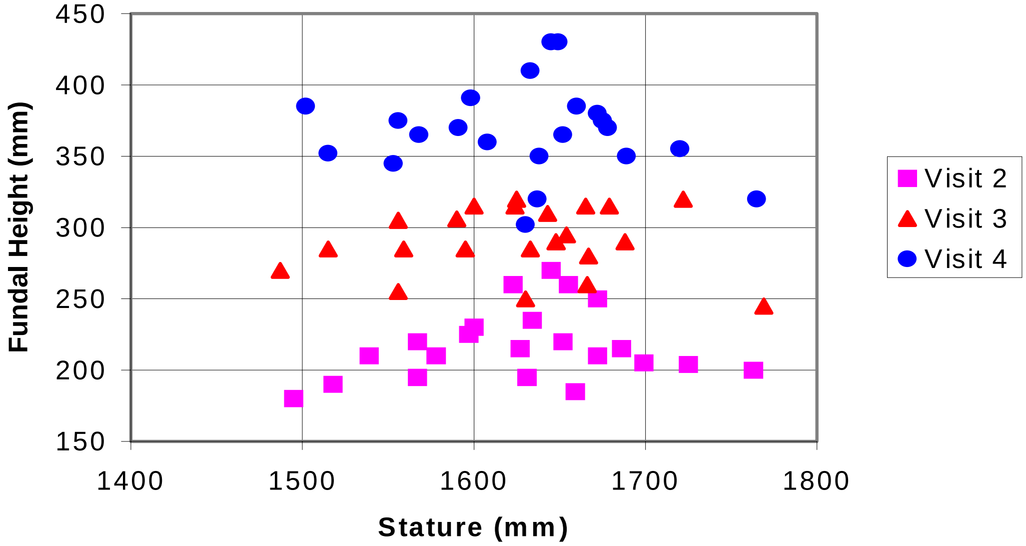


Figure 19. Fundal height vs. stature (r=0.000).

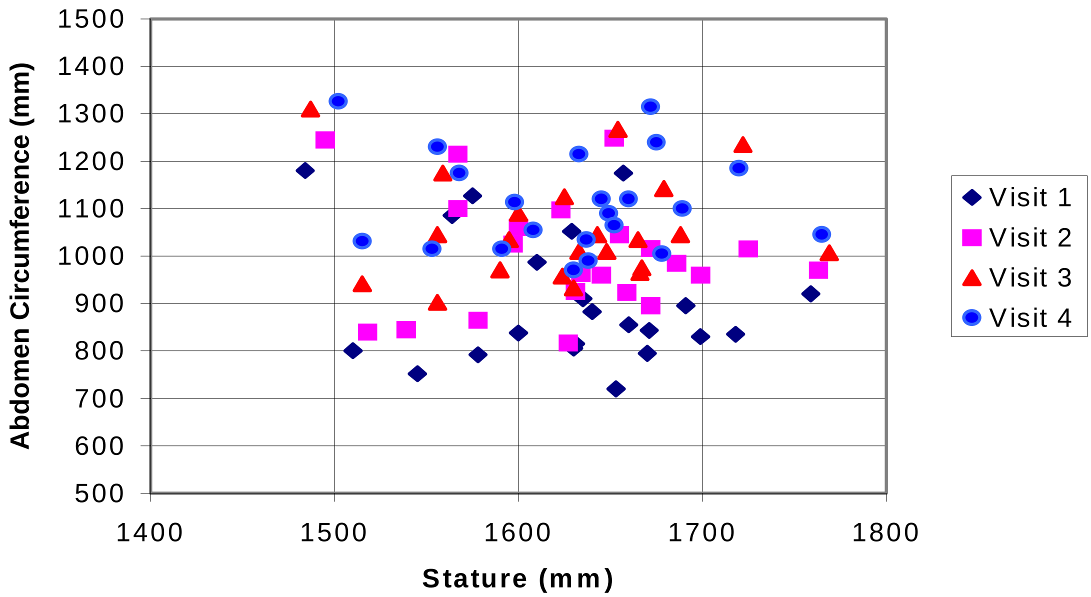


Figure 20. Abdomen circumference vs. stature (r = 0.114).

The anthropometric variables from the initial test session were also studied with respect to the subject's weight in the first test session. As expected, the arm length, forearm length, arm reach, posterior superior iliac spine (PSIS) height, sitting height, popliteal height, and knee height did not show any correlation with weight. The measures taken at each test session (provided in Table E1 of Appendix E) of hip breadth, ASIS breadth, buttock-knee length, buttock-popliteal length, abdomen depth, and abdomen circumference showed a correlation with subject weight measured on the first visit. In addition, they increased as the subjects gained weight over the course of their pregnancies.

Figures 21, 22, and 23 show scatter plots of abdomen depth, abdomen circumference, and fundal height versus weight for the four test sessions of each subject. Abdomen depth and circumference show a positive correlation with subject weight, while fundal height does not.

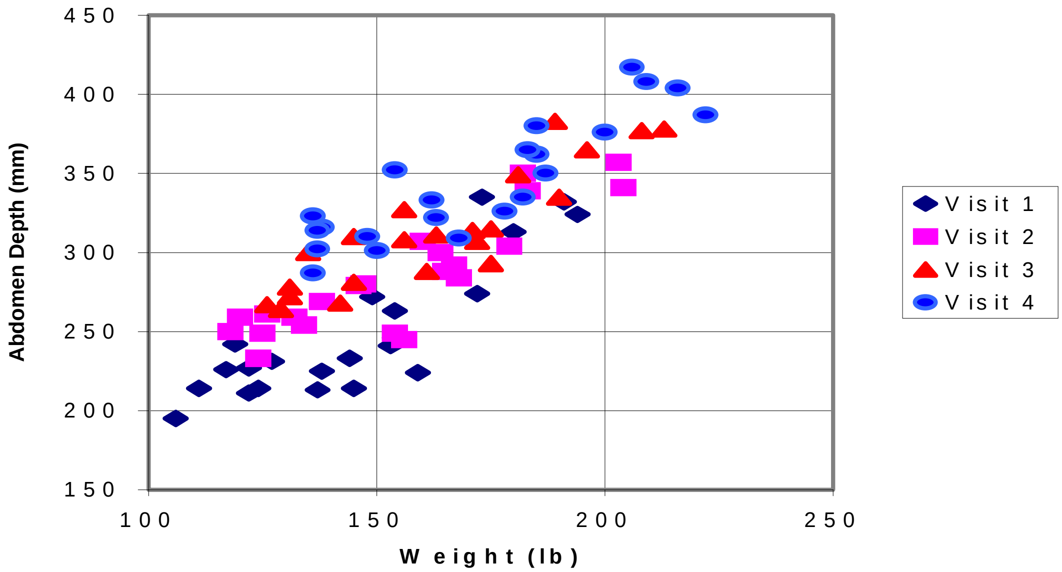


Figure 21. Abdomen depth vs. weight for test sessions 1 through 4 (r=0.807).

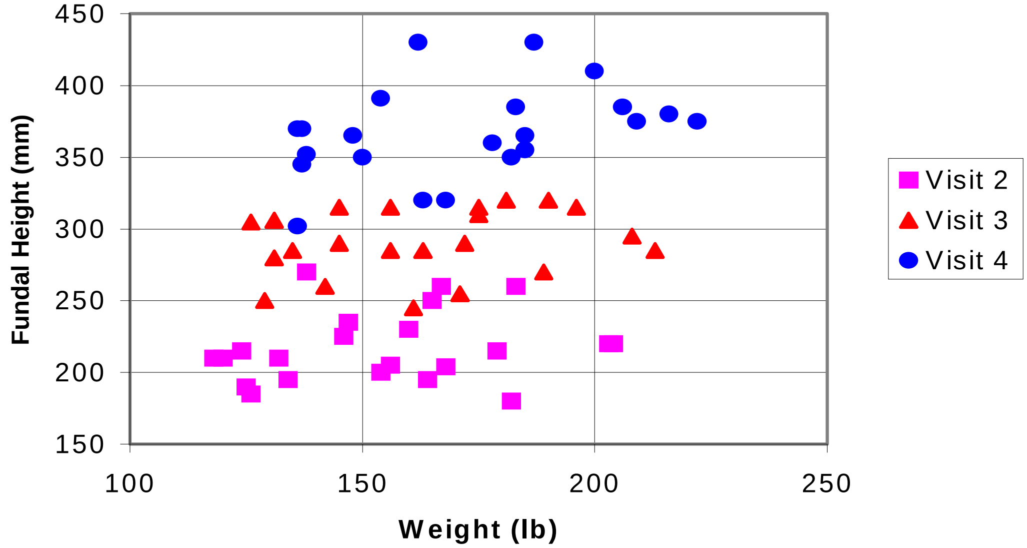


Figure 22. Fundal height vs. weight for test sessions 1 through 4 (r=0.352).

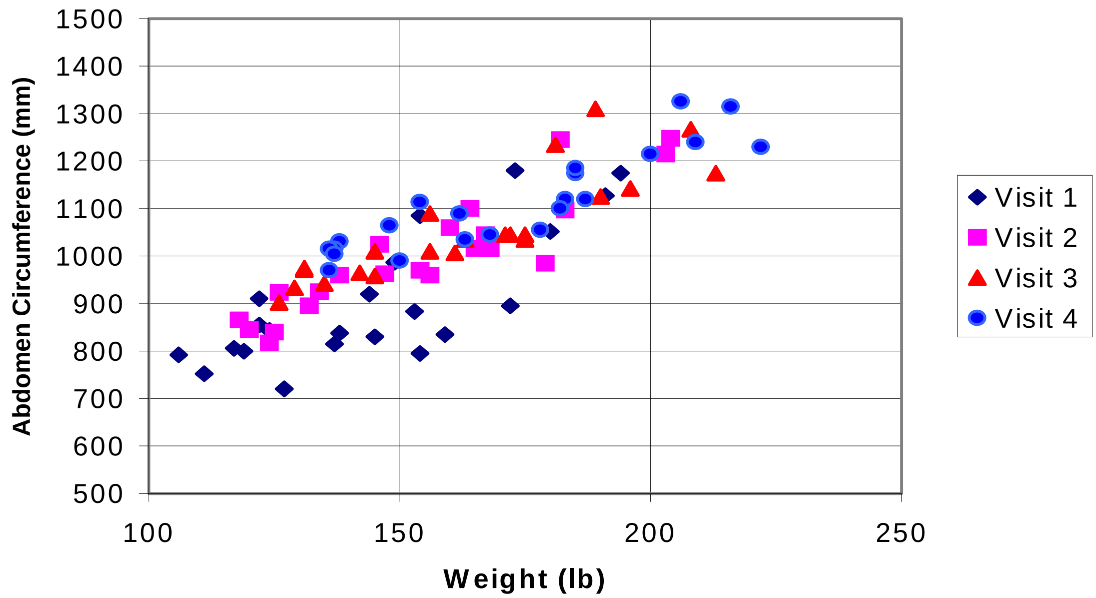


Figure 23. Abdomen circumference vs. weight for test sessions 1 through 4 (r=0.863).

3.2 Preferred Seat and Steering-Wheel Positions

Table 8 summarizes mean values for the subject-selected seatback angle for each seat height, stature group, and test session. The seatback angle is based on the angle measured with the SAE J826 H-point manikin. As seen in Figure 24, the mean seatback angles averaged over all test configurations and stature groups at each gestational age are different (p=0.043), but no clear trend of increasing or decreasing angle with gestational age is seen. Also, no statistically significant variation of seatback angle with stature was found.

Table 8
Mean Values for Seatback Angles (deg)

H30=270 mm						
	Group 1	Group 2	Group 3	Group 4	Group 5	Mean
Session 1	18.4	14.8	14.9	18.1	13.6	16.2
Session 2	16.8	14.9	14.6	19.4	16.4	16.7
Session 3	13.0	12.1	15.7	17.2	13.4	14.2
Session 4	14.8	14.3	15.7	16.9	13.4	14.5
Mean	16.4	14.0	15.2	17.9	13.5	15.4
H30=360 mm						
	Group 1	Group 2	Group 3	Group 4	Group 5	Mean
Session 1	14.1	15.1	16.9	15.7	14.4	15.3
Session 2	16.1	16.6	14.9	16.8	15.6	16.3
Session 3	13.2	15.3	17.2	17.1	12.7	15.0
Session 4	15.4	15.8	16.3	18.0	15.2	15.6
Mean	15.4	15.7	16.3	16.7	13.7	15.6

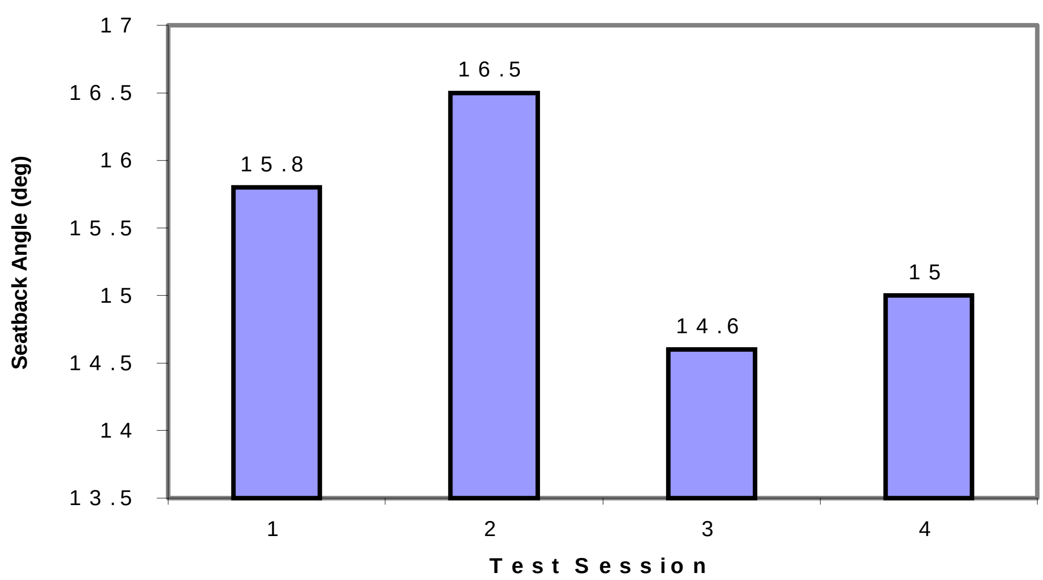


Figure 24. Mean seatback angle by test session for all stature groups and test configurations.

Table 9 lists mean values for the seat fore/aft position in the form of H-point-to-ball-of-foot (BOF) distance, with greater distances indicating more rearward seat positions. Figure 25 shows overall mean values of seat position for all test sessions by stature group. As expected, taller subjects positioned the seat more rearward (p=0.001). As seen when comparing the upper and lower portions of Table 9, subjects positioned the seat more rearward for the 270-mm seat height configurations compared to the 360-mm seat-height configurations (p<0.0001), with overall mean values of 848 mm versus 807 mm, respectively. However, the variation in H-point-to-BOF distance (down each column of Table 9) with gestational age is not statistically significant for any subject group.

Table 9
Mean Values for H-point-to-BOF

H30=270 mm						
	Group 1	Group 2	Group 3	Group 4	Group 5	Mean
Session 1	782	819	861	843	903	843
Session 2	783	840	838	849	913	845
Session 3	788	838	843	848	914	847
Session 4	708	846	845	856	926	855
Mean	790	836	847	847	919	848
H30=360 mm						
	Group 1	Group 2	Group 3	Group 4	Group 5	Mean
Session 1	759	777	798	820	861	805
Session 2	758	779	799	814	869	804
Session 3	765	791	799	798	874	806
Session 4	778	804	805	811	875	815
Mean	766	788	800	810	875	807

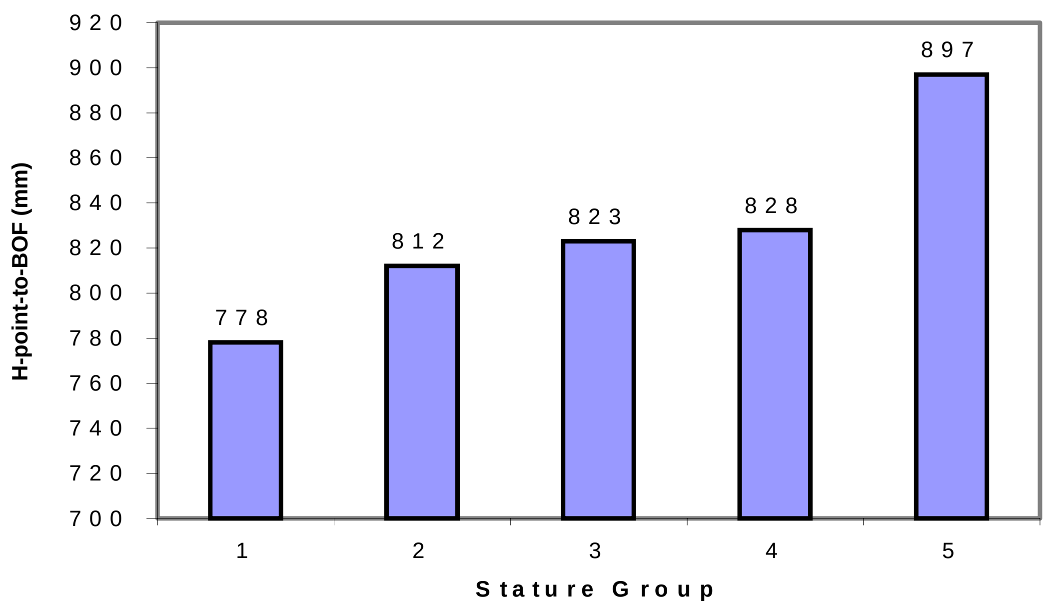


Figure 25. H-point-to-BOF distance by stature group for all test sessions and configurations.

Steering-wheel tilt angle, shown in Table 10, does not change significantly with gestational age or subject stature. However, the mean angles for each stature group are slightly higher (i.e., more horizontal) for the 360-mm seat height compared to the 270-mm seat height ($p<0.0001$), with overall mean values of 26.3° vs. 28.7°. This result is similar to observations made for non-pregnant drivers in other UMTRI studies (Manary 1999).

Table 10
Mean Values for Steering-Wheel Tilt Angle

H30=270 mm						
	Group 1	Group 2	Group 3	Group 4	Group 5	Mean
Session 1	25.6	24.4	25.8	30.1	22.8	26.2
Session 2	27.0	24.3	26.8	29.8	23.8	25.4
Session 3	29.0	24.9	25.1	29.2	23.7	28.9
Session 4	30.5	28.0	26.4	30.5	23.3	28.0
Mean	26.4	26.5	27.5	30.6	24.4	26.3
H30=360 mm						
	Group 1	Group 2	Group 3	Group 4	Group 5	Mean
Session 1	30.2	29.8	28.2	30.1	23.9	26.6
Session 2	29.1	27.7	28.6	31.6	26.6	27.1
Session 3	31.0	28.3	29.2	31.5	25.2	28.3
Session 4	30.5	29.3	29.6	32.2	24.8	29.8
Mean	28.5	27.6	27.7	31.2	24.7	28.7

3.3 Abdomen Location Relative to Steering Wheel

Two different calculations were made to quantify the relationship between the pregnant occupant's abdomen and the steering wheel and airbag module. The methods are illustrated in Figure 26. Abdomen-to-wheel clearance is the minimum distance between the subject's midline abdomen contour and the bottom of the steering-wheel rim. Uterus-to-wheel overlap is the proportion of the pregnant uterus that lies above the bottom of the steering-wheel rim.

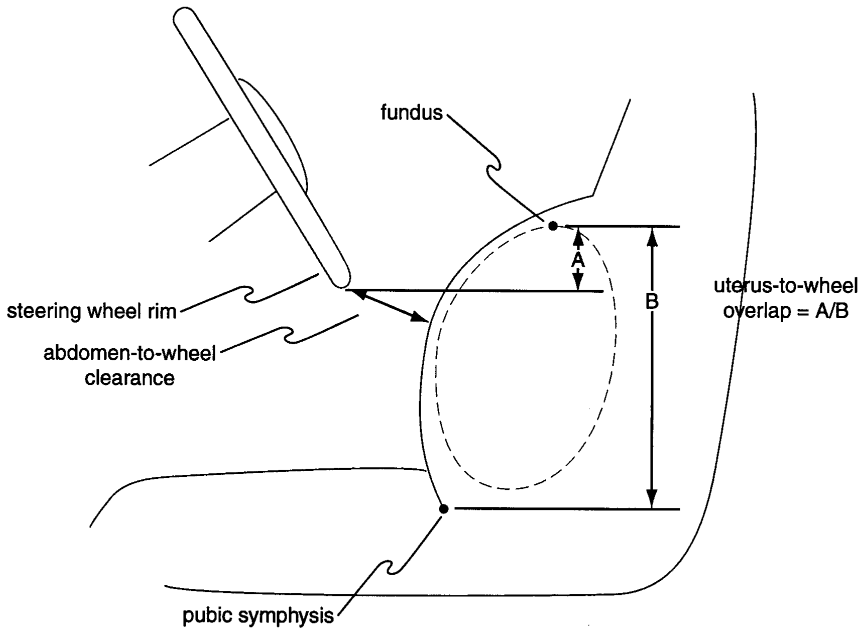


Figure 26. Illustration of abdomen-to-wheel clearance and uterus-to-wheel overlap.

Mean abdomen-to-wheel clearance by gestational age for each stature group is shown in Figures 27 and 28 for the two seat heights, respectively. At both seat heights, abdomen-to-wheel clearance decreases with gestational age ($p<0.0001$). The differences in clearance for the two seat heights are insignificant ($p=0.095$). Figure 29 indicates that the mean clearance for all subjects and configurations at the first test session is 138.5 mm, but decreases to 58.5 mm in the last month of pregnancy. Figure 30 shows that, as expected, the shortest subjects have the smallest clearances, while the tallest subjects have the largest clearances ($p=0.006$) when averaged over all test sessions. At the fourth test session, the Group 1 clearance averages 25 mm, while the Group 5 mean clearance is 110 mm.

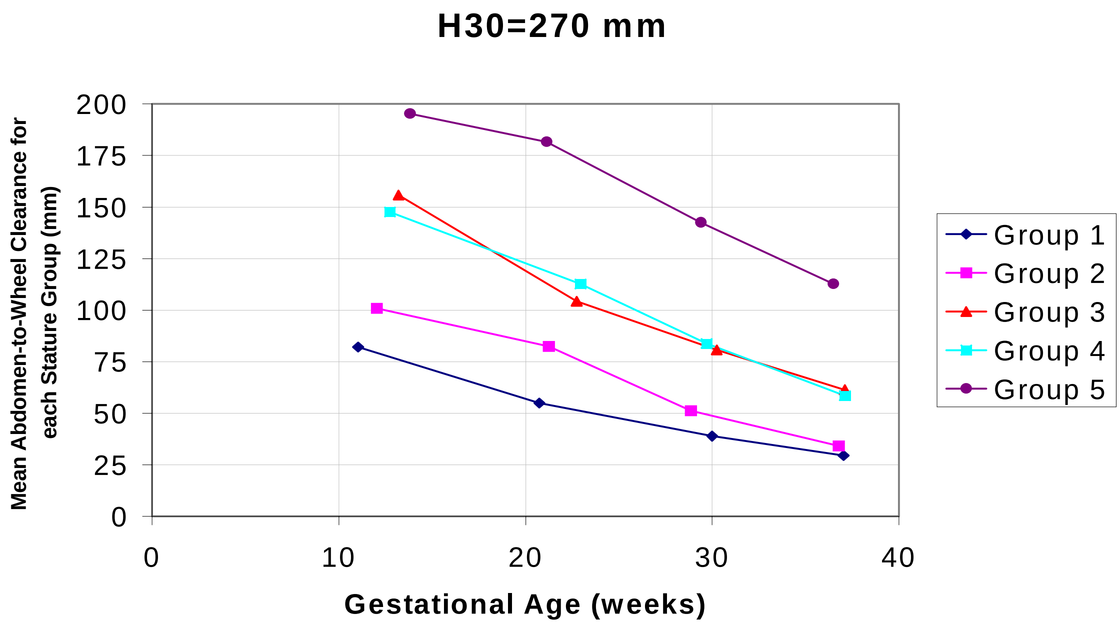


Figure 27. Mean abdomen-to-wheel clearance by gestational age for each stature group for 270-mm seat-height configurations.

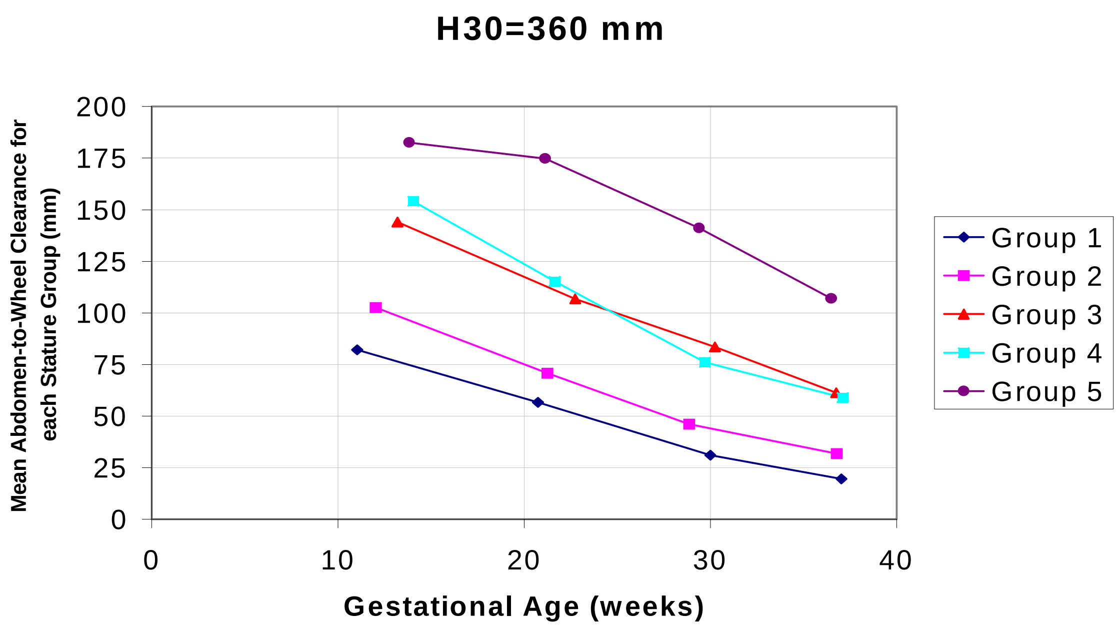


Figure 28. Mean abdomen-to-wheel clearance for each stature group by gestational age for 360-mm seat-height configurations.

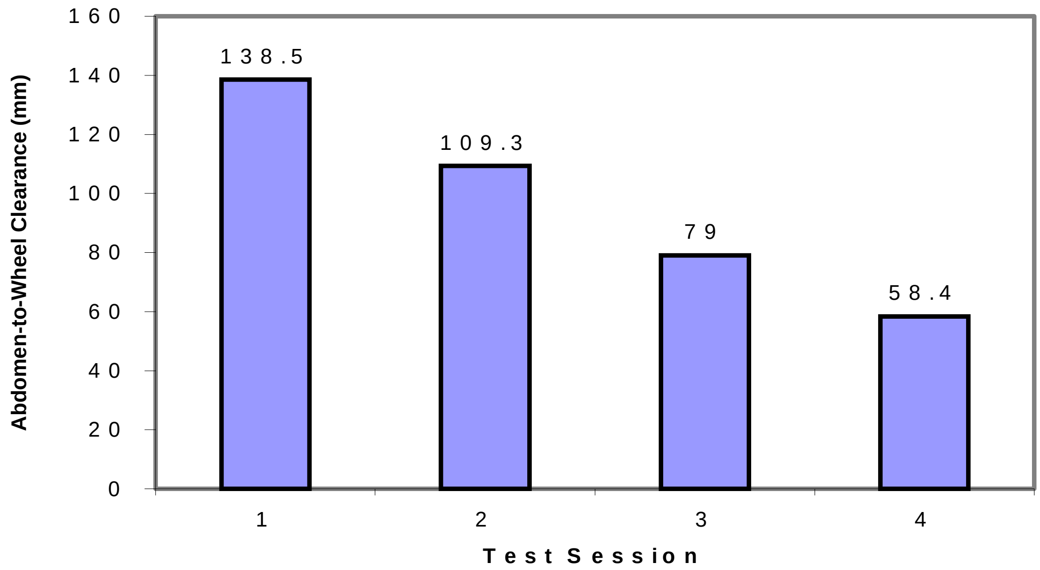


Figure 29. Mean abdomen-to-wheel clearance by test session for all subjects and configurations.

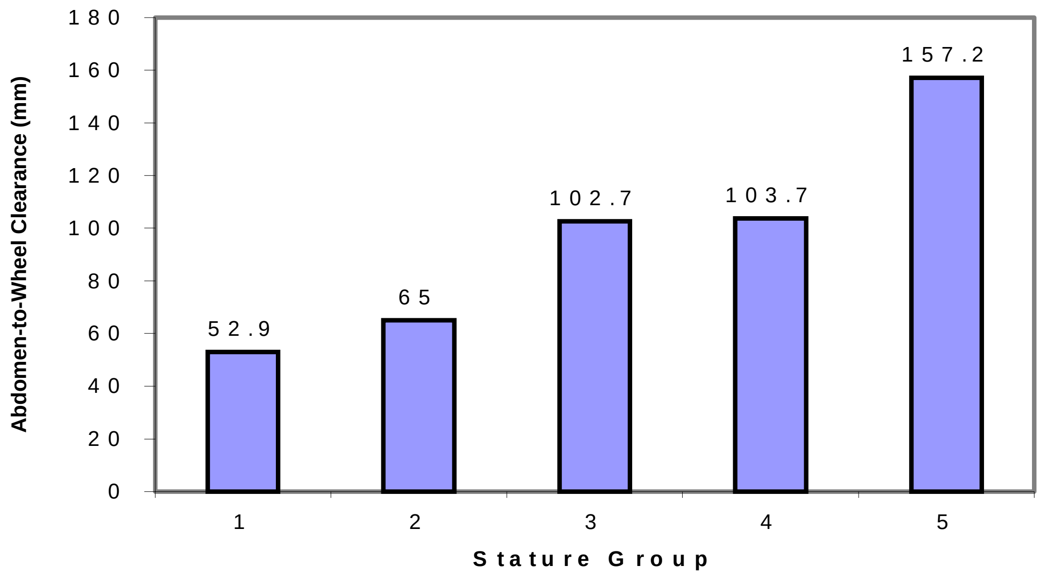


Figure 30. Mean abdomen-to-wheel clearance by stature group for all test sessions and configurations.

Figures 31 and 32 show plots of uterus-to-wheel overlap versus gestational age for the second through the fourth test sessions for each seat height. Figure 33 shows the mean values for both seat heights combined by stature group and test session, plus a plot of the overall mean of all subjects and test configuration by test sessions. Uterus-to-wheel overlap was not calculated for the first test session since the fundus is not reliably located this early in pregnancy. The overlap increases with gestational age ($p<0.0001$), with barely noticeable overlap at the second test session. The uterus overlaps the wheel to a somewhat greater extent at the 360-mm seat height ($p<0.0001$), with mean values for all test sessions of 15.8% in the 270-mm configurations versus 19.9% for the 360-mm configurations. At the last test session, uterine overlap with the steering wheel averages 26% for all stature groups.

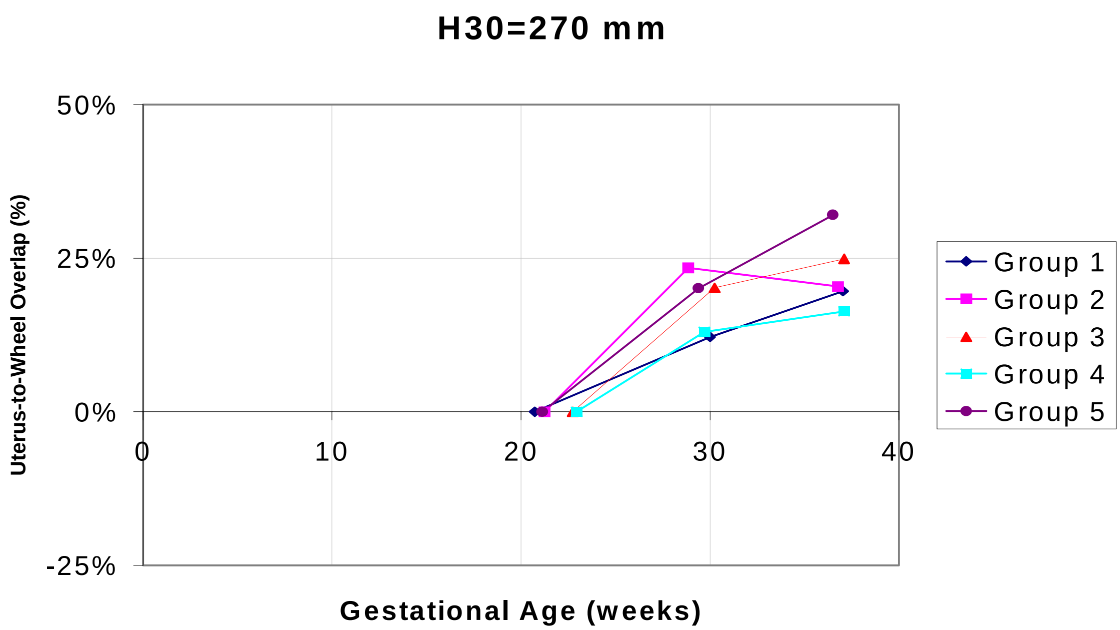


Figure 31. Mean uterus-to-wheel overlap for each stature group by gestational age for 270-mm seat-height configurations.

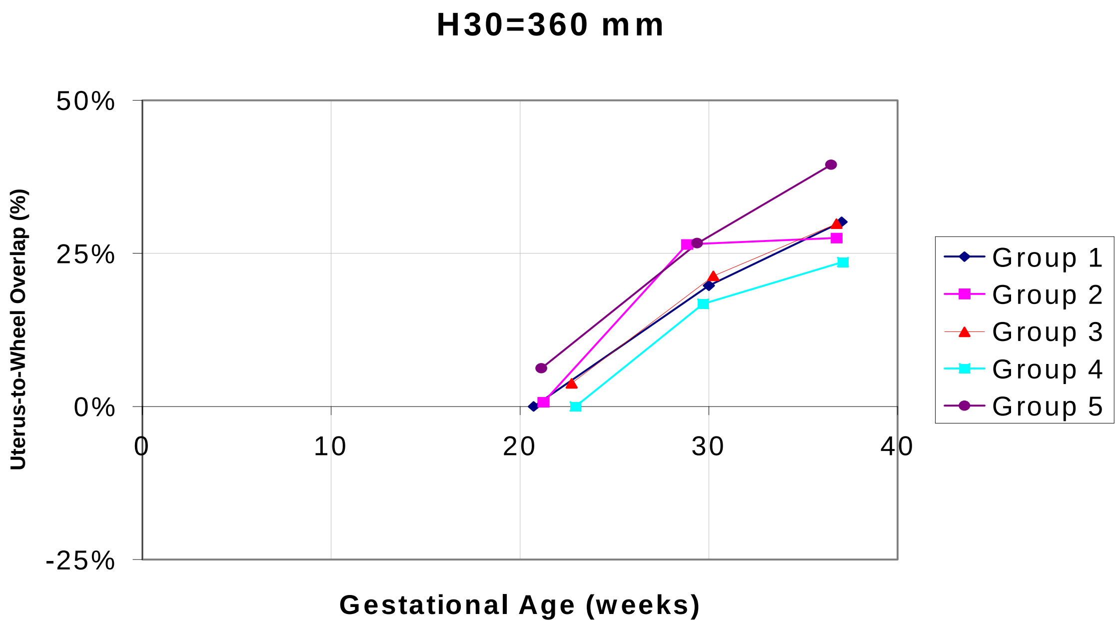


Figure 32. Mean uterus-to-wheel overlap for each stature group by gestational age for 360-mm seat-height configurations.

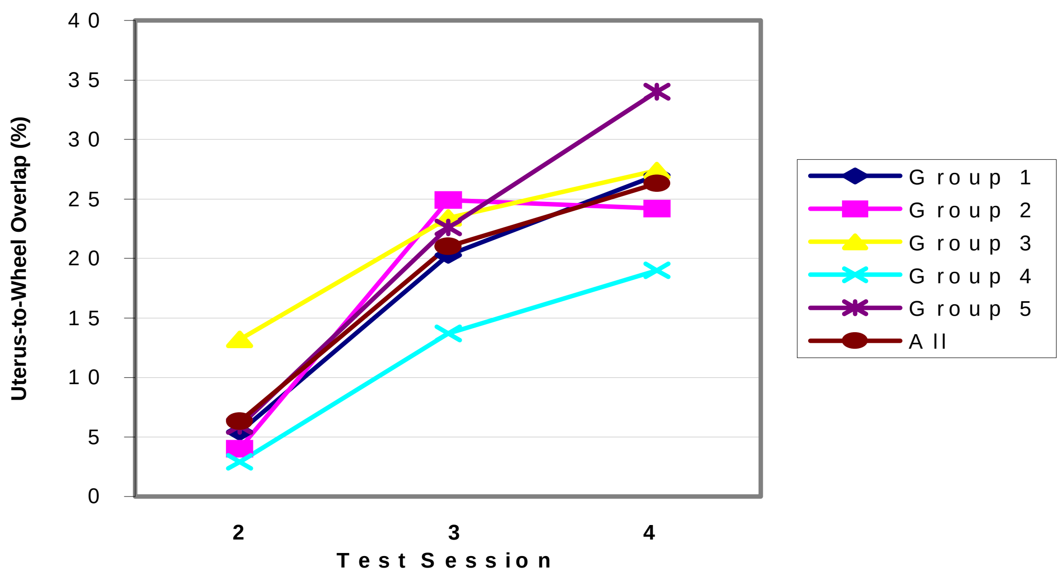


Figure 33. Mean uterus-to-wheel overlap by test session for each stature group plus the overall mean for all subjects by test session.

3.4 Abdomen Contours

The side-view profile of the pregnant abdomen in the laboratory seating buck was established by digitizing the pubic symphysis, the xiphoid process, and eight points along the abdomen midline between these two points. To compare these midline abdomen contours independently of occupant position and stature, the digitized contour data for each subject were first shifted along the x and z axes to overlay the pubic symphysis points. They were then rotated so that a line between the pubic symphysis and xiphoid was oriented at an angle of 60° relative to horizontal (chosen arbitrarily to approximate a typical angle while seated). This rotation averaged 4° across all subjects. The contours of each subject's abdomen in the four test configurations of each session were aligned in this manner. Visual inspection indicated that the abdomen contours did not vary substantially with test conditions. A single abdomen contour for each subject and test session was therefore calculated by averaging the shifted and rotated x-z coordinates of the abdomen contour points.

Plots of the mean abdomen contour for each subject are shown in Appendix F. Each plot contains the mean abdomen contour for the subjects in a single stature group at a single test session. The line connecting the pubic symphysis and the fundus is shown to allow easier visualization of the fundal location. Some variability in abdomen shapes exists between subjects in each stature group at each test session, but the variability within each stature group appears to decrease by the last test session. Each group has one or two subjects with an unusually shaped abdomen, but in general, these data show similarities among pregnant abdomen shapes that are independent of stature.

Abdomen contour data from the third test session were used to specify the external contour for the second-generation pregnant abdomen. The average gestational age at this test session of thirty weeks is closest to the target gestational age for the dummy of seven months. The size of this test dummy corresponds to a small female who is approximately 5th percentile in U.S. population height and weight (Abraham 1979). Figure 34 is a composite plot of the mean abdomen contours for all subjects from the third test session.

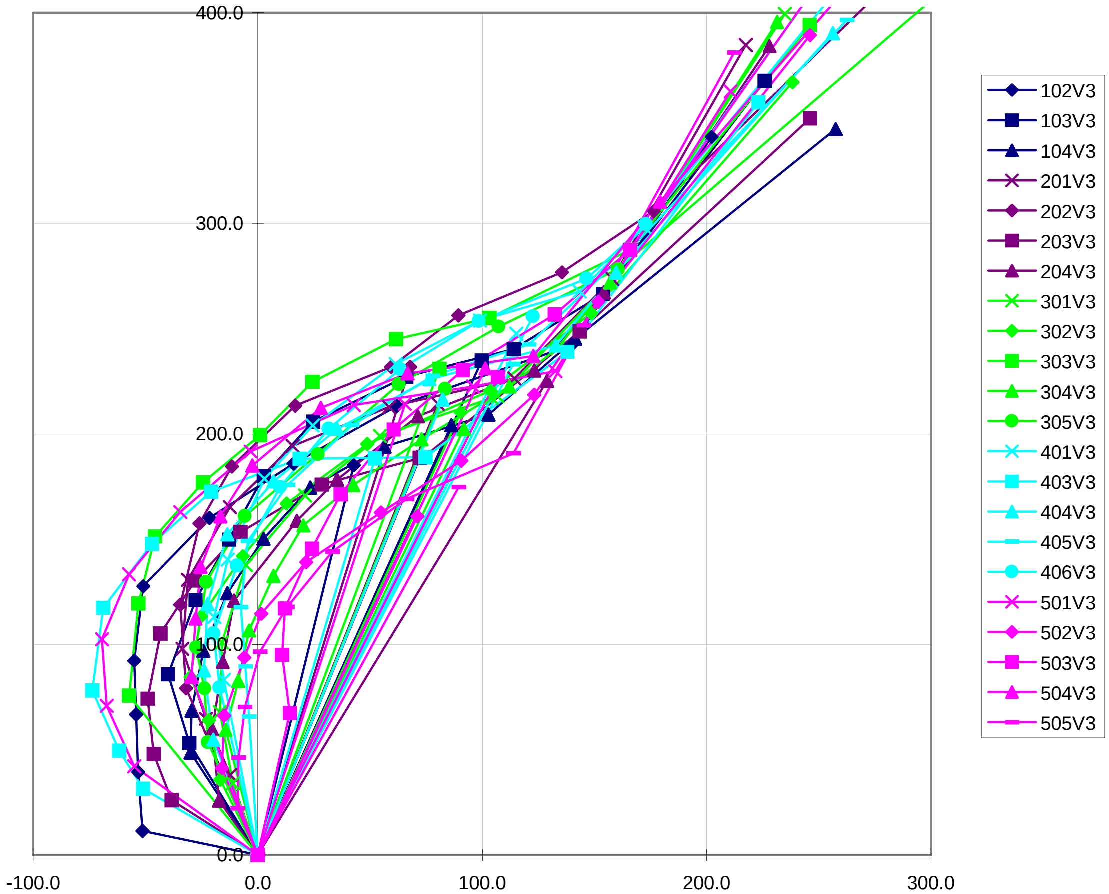


Figure 34. Composite plot of all abdomen contours from the third test session. Straight lines indicate the fundal location relative to the pubic symphysis.

Several different strategies were explored to determine the contour for the pregnant abdomen of the small-female ATD. Because the "pregnancy" measurements of abdomen depth, abdomen circumference, and fundal height did not show a correlation with subject stature, the analysis was not limited to data from small subjects. For the same reason, scaling of the abdomen contours according to stature did not seem appropriate or necessary

The first approach involved averaging the abdomen contours of all subjects from the third test session. The second approach involved discarding the contours of nine subjects who had unusually large, small, or different-shaped abdomen contours based on visual inspection of the contours. This set of contours with the "outliers" removed is shown in Figure 35. A third approach involved using contour data from subjects whose abdomen depth was within a half of a standard deviation of the mean abdomen depth for all subjects. This led to selection of subjects with abdomen depths from 294 to 332 mm. These contours are plotted in Figure 36. Visual inspection led to the further removal of the two contours that are of different shape than the rest. All of these remaining contours were also included with the group used in the second approach. The fourth approach limited the contours used to subjects who were not overweight, since the small female dummy represents a short, relatively thin woman. Subjects were considered not overweight if they had a BMI of less than 25 in the first test session, and gained no more than 22 pounds by the third session. Figure 37 illustrates the contours from these subjects. Six of these eight subjects were also included in the second approach, while only two were included in the third approach.

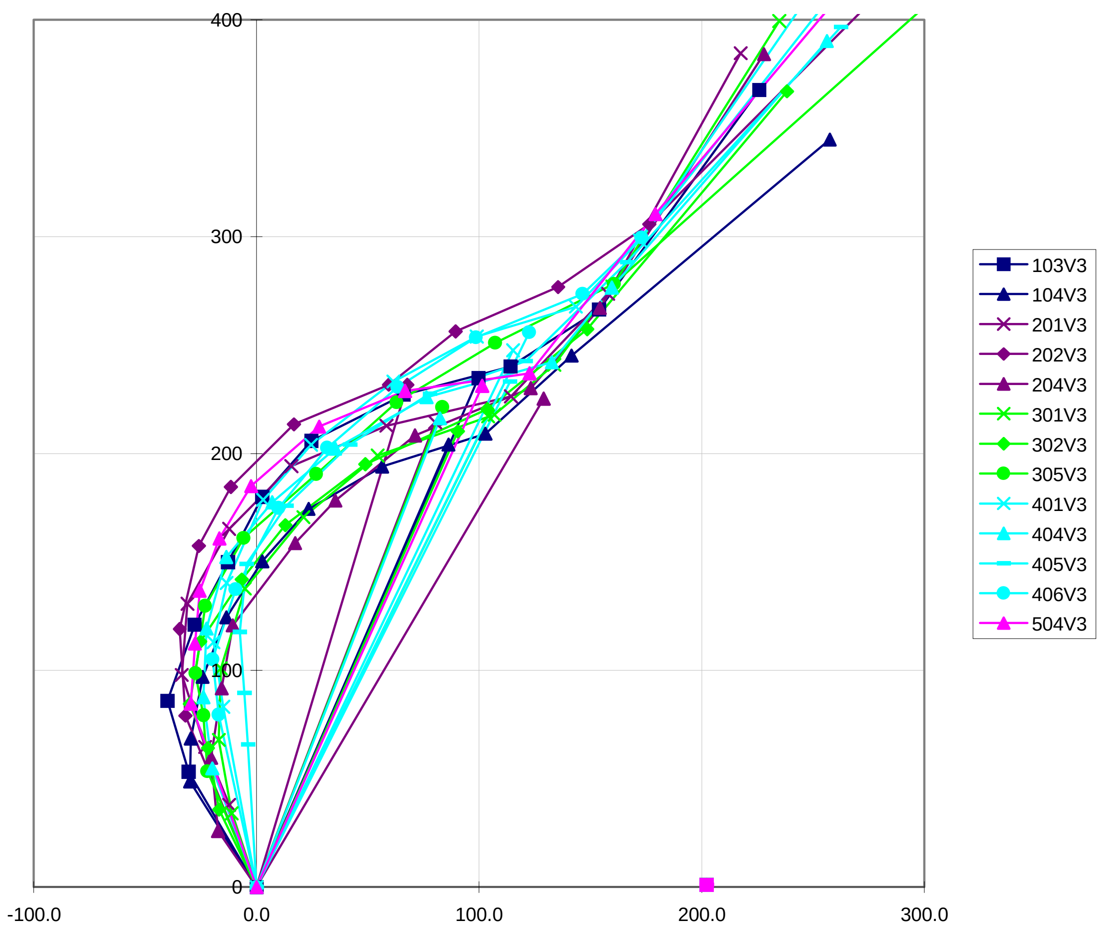


Figure 35. Abdomen contours for third test session with “outliers” removed.

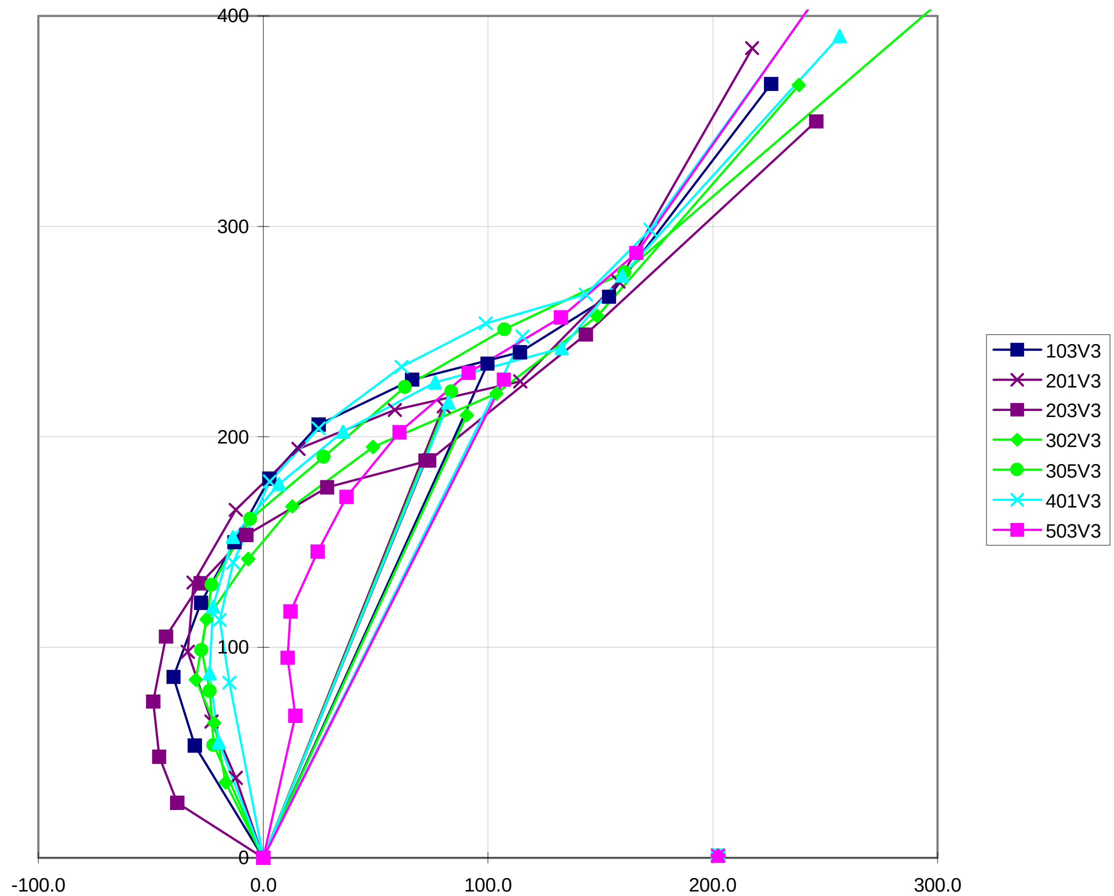


Figure 36. Abdomen contours for third test session of subjects with abdomen depths close to the mean for all subjects.

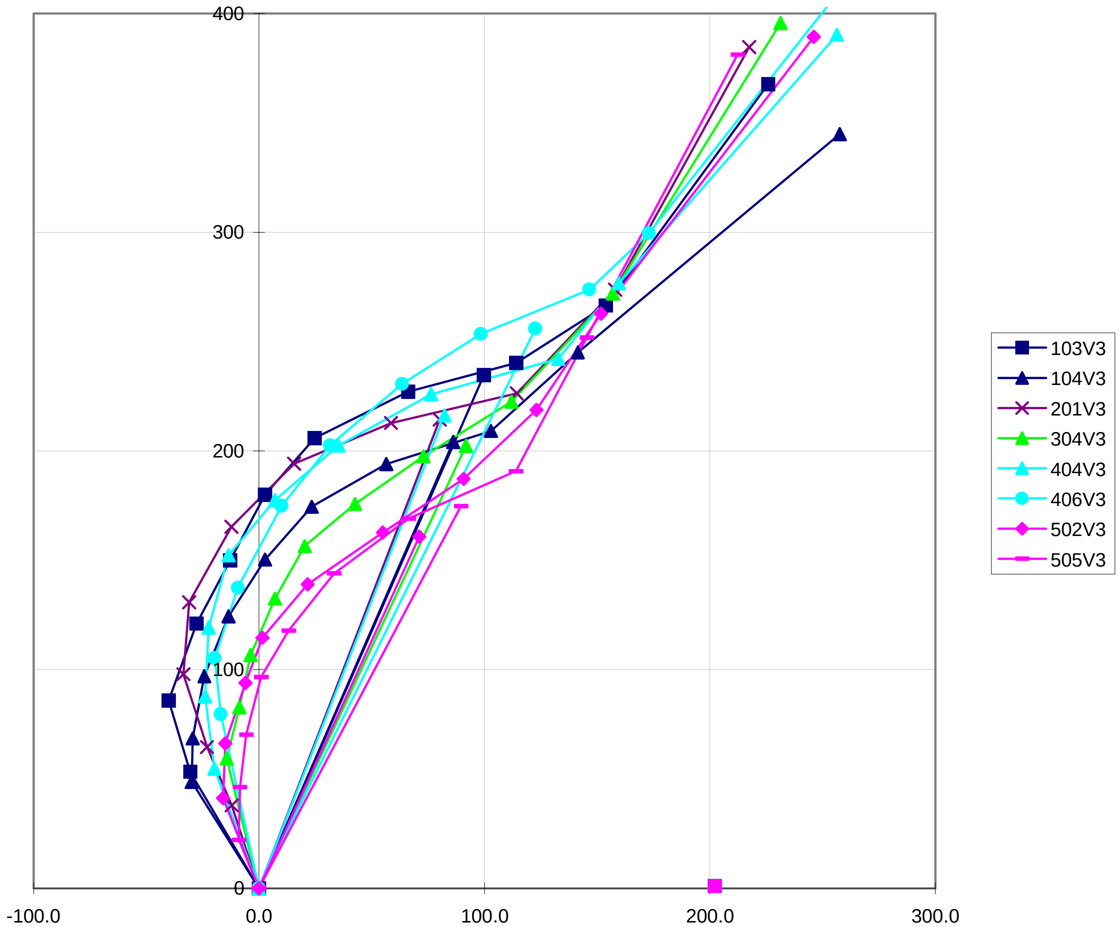


Figure 37. Abdomen contours for third test session of "thin" subjects.

Average contours calculated for the four different approaches are plotted in Figure 38. In general, the average contours are quite similar, and it therefore does not matter which approach is used for determining the ATD abdomen contour. The average contour for the thin subjects is slightly smaller, and the average contour for all subjects protrudes somewhat more near the bottom. However, the differences between shapes are less than a centimeter at any point. For this reason, the shape based on all subjects was selected for use in the design of the new pregnant abdomen.

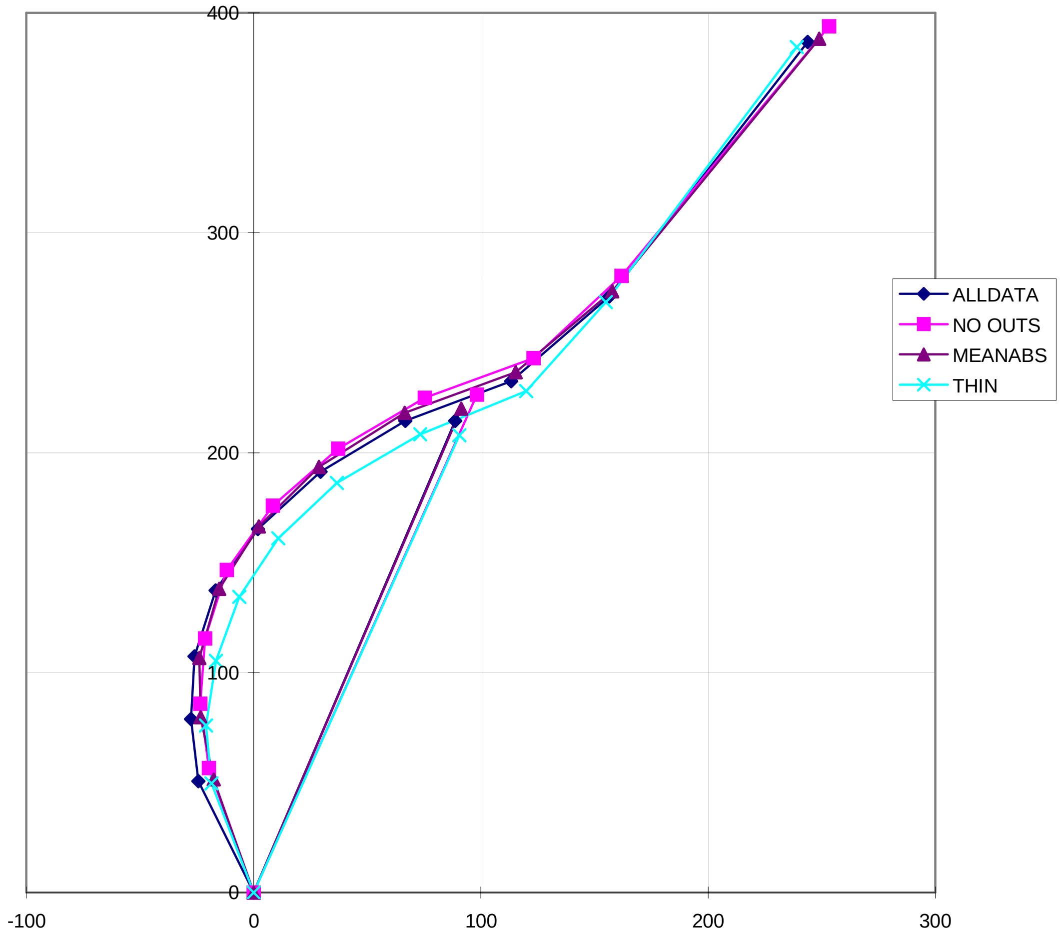


Figure 38. Comparison of mean abdomen contours for the four approaches using data from the third test session.

Figure 39 compares the proposed pregnant abdomen contour with the side-view profile of the first-generation pregnant abdomen. The first-generation pregnant abdomen shape clearly is not realistic. It is suspected that it was primarily based on a need to keep the pregnant abdomen completely below the ribcage of the small female ATD rather than on pregnant anthropometric data.

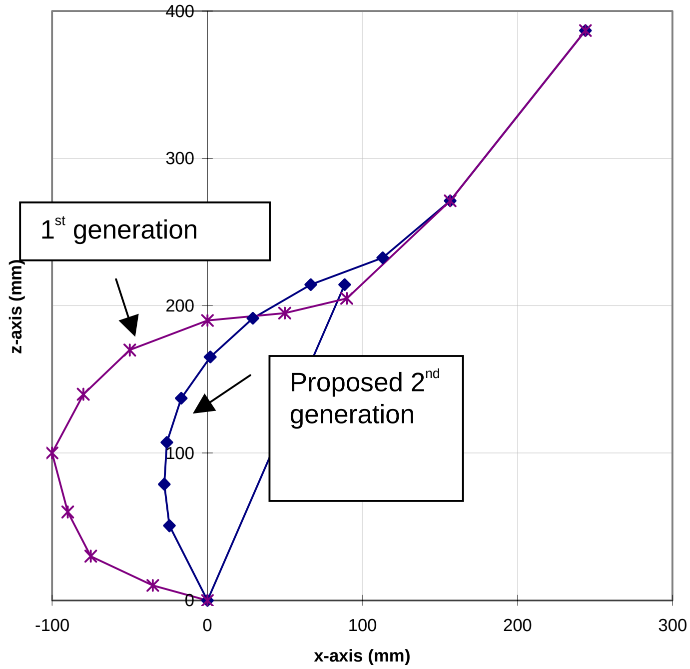


Figure 39. Proposed abdomen contour of second-generation pregnant abdomen compared to the side-view profile of the first-generation pregnant abdomen.

3.5 Occupant Posture and Abdomen Contours

The digitized landmarks collected during testing were processed using procedures developed by Reed et al. (1999) to generate approximations to the joint centers of the subjects. These joint centers, together with some of the landmarks, were used to describe subject postures that can be represented by stick-figure drawings. An average posture and abdomen contour for each stature group and seat height was generated by averaging the joint-center coordinates and using the mean subject-group abdomen contour for all subjects within each stature group tested at each seat height. Plots of the average posture and abdomen contour for each stature group and seat height are provided in Appendix G. Each plot includes a stick-figure representation for all four test sessions. In general, the average seated postures and positions at each gestational age are similar within a stature group. The most obvious change is in the abdomen contour, which results in a decreasing distance between the abdomen and steering-wheel rim as gestational age increases.

A statistical analysis of body segment and joint angles was performed to examine differences with seat heights, subject stature, and gestational age. These segment and joint angles are defined in Figure 40. Angles referenced to the horizontal or vertical are x-z (sagittal) plane angles. Joint angles between body segments are measured in the plane formed by the segments. Orientation of the limbs out of the sagittal plane is described by splay angles defined by Reed et al. (1999).

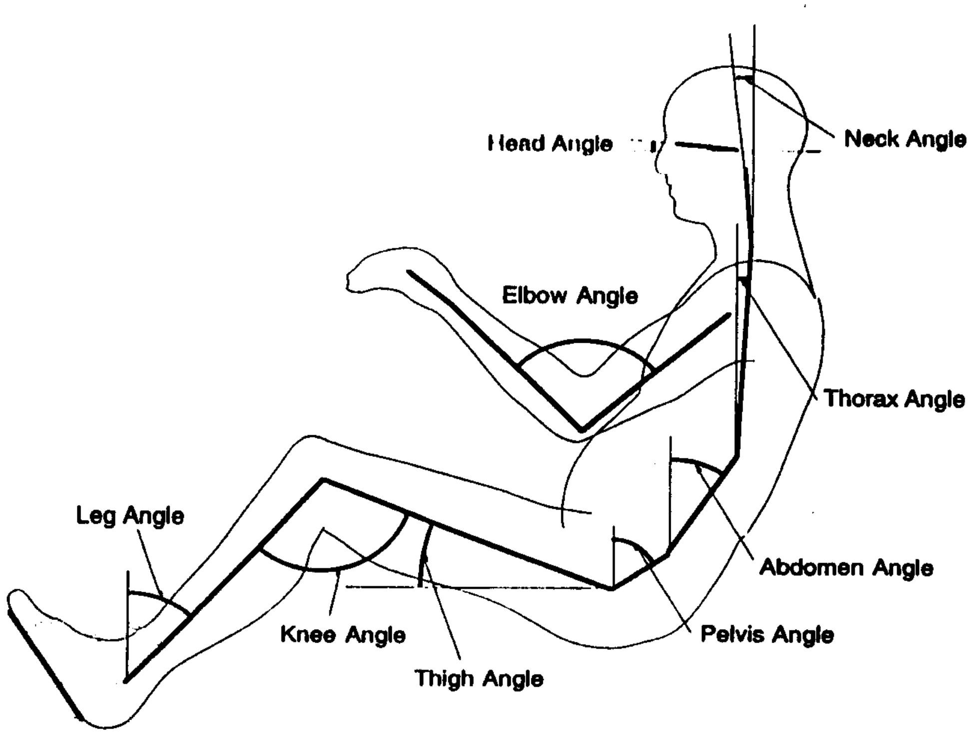


Figure 40. Posture angle definitions (Reed et al. 1999).

Table 11 shows mean values for segment and joint angles that are statistically different by seat height, along with associated p-values. At the 360-mm seat height, the abdomen is slightly more reclined, the arm is more extended and the elbow further from the body, the thigh is angled slightly more outward and the leg slightly more inward, while the knee is extended less.

Table 11

Means and p-values for Posture Angles that Vary Significantly with Seat Height

	H30=270 mm	H30=360 mm	p value
abdomen angle	30.0	31.9	0.000
thigh splay	20.2	20.9	0.007
leg splay	15.7	13.6	0.002
knee angle	121.1	115.9	0.000
arm splay	37.8	41.3	0.002
elbow angle	113.5	118.2	0.000

Table 12 lists the mean values for segment and joint angles that vary significantly with gestational age, along with associated p-values. Subjects selected more reclined torso angles over the course of their pregnancy, but their abdomen or lumbar region was more upright. These measurements show some change in subject posture even though seatback angle did not change with gestational age. The leg splay angle increased as gestational age increased.

Table 12

Means and p-values for Posture Angles that Vary Significantly with Gestational Age

	Session 1	Session 2	Session 3	Session 4	p-value
thorax angle	-0.6	1.0	2.9	4.7	0.001
abdomen angle	34.0	32.1	28.4	29.3	0.006
leg splay angle	12.3	13.7	15.0	17.5	0.003

Head angle varies with subject stature (p=0.003), such that the tallest subjects appeared to position their heads to look more downward than the shorter subjects. This finding is somewhat inconsistent from other UMTRI seating studies, and may result from the new driving simulator installed for this study, because the screen is positioned lower than other projected driving scenes.

3.6 Lap- and Shoulder-Belt Angles

As noted in the Methods, nominal lap-belt angles of 40° and 60° and nominal shoulder-belt angles of 20° and 60° were used in the test matrix. The actual angle of the belt on a subject depends on the anchorage location, the selected fore/aft seat position, and the subject's anthropometry. The actual lap-belt angle for each subject was calculated using the digitized point on the belt centerline closest to the outboard anchor point and the forwardmost point digitized on the lap belt. The actual shoulder-belt angle was calculated using the digitized shoulder anchor point (e.g. anchor bolt of D-ring) and the estimated center of the subject's shoulder. The center-of-shoulder point is located midway between the digitized neck/shoulder junction and the calculated left greater tubercle of the humerus (based on locations of the left and right acromion and right greater tubercle of the humerus).

The mean lap-belt angles for each stature group and seat position as a function of gestational age are illustrated in Figures 41 and 42. Figure 43 shows the average lap-belt angles by test session for all subjects at each seat height. For both seat heights, the lap-belt angle decreases (i.e., becomes more horizontal) with increasing gestational age for all stature groups (p<0.0001). The overall mean angle changes from 56.8° at the first test session to 45.0° for the last test session. Since the belt anchorage is fixed, but the forwardmost point of the lap belt moves forward with the growing pregnant abdomen, some decrease in angle with gestational age is expected. At the first two test sessions, the lap-belt angle is more vertical for the 360-mm seat height by approximately 2° (p=0.020).

Figure 44 illustrates the mean lap-belt angle by subject stature including all test configurations and sessions. Overall, lap-belt angle is greater for the taller subjects who sit rearward ($p=0.029$), with a mean difference of nearly 10° between Group-1 and Group-5 subjects, averaged over all conditions and test sessions. Overall, the two nominal lap-belt angles of 40° and 60° resulted in mean angles of 46° and 55.2°, respectively ($p<0.0001$).

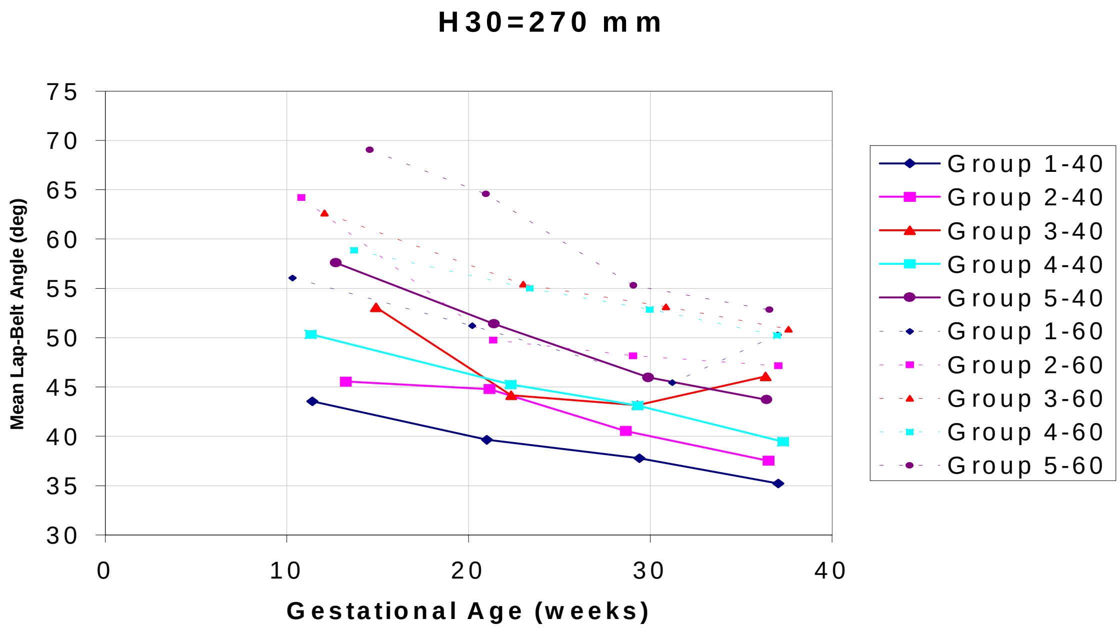


Figure 41. Mean actual lap-belt angles by gestational age for each stature group and nominal belt-angle condition for the 270-mm seat-height configurations. Dashed lines correspond to the 60° nominal lap-belt angle, while solid lines designate the 40° lap-belt angle.

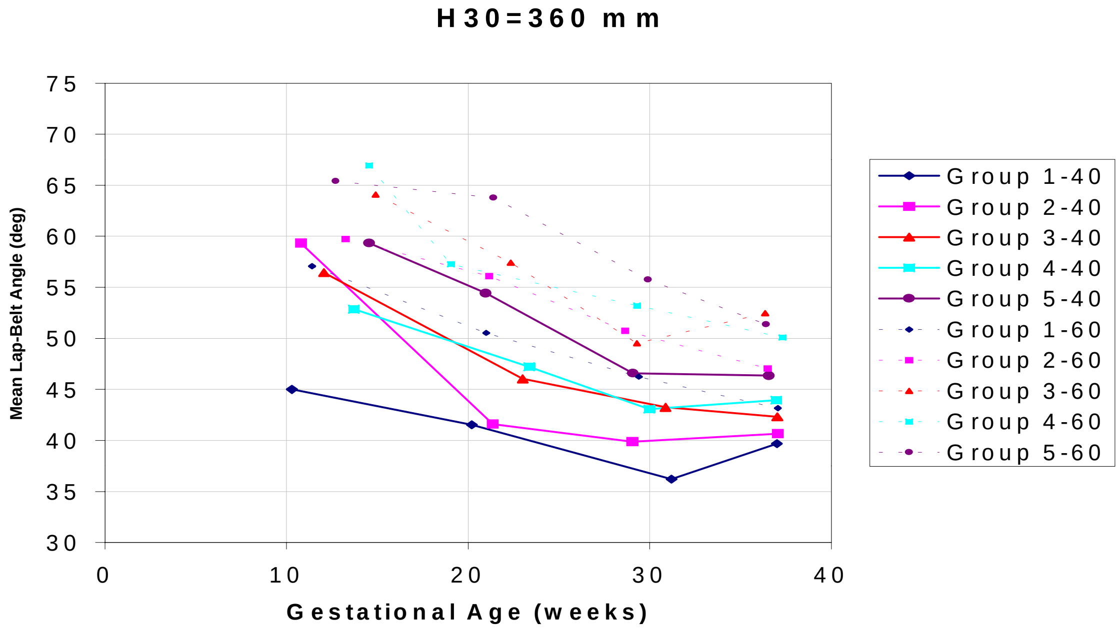


Figure 42. Mean actual lap-belt angles by gestational age for each stature group and nominal belt-angle condition for the 360-mm seat-height configurations. Dashed lines correspond to the 60° nominal lap-belt angle, while solid lines designate the 40° lap-belt angle.

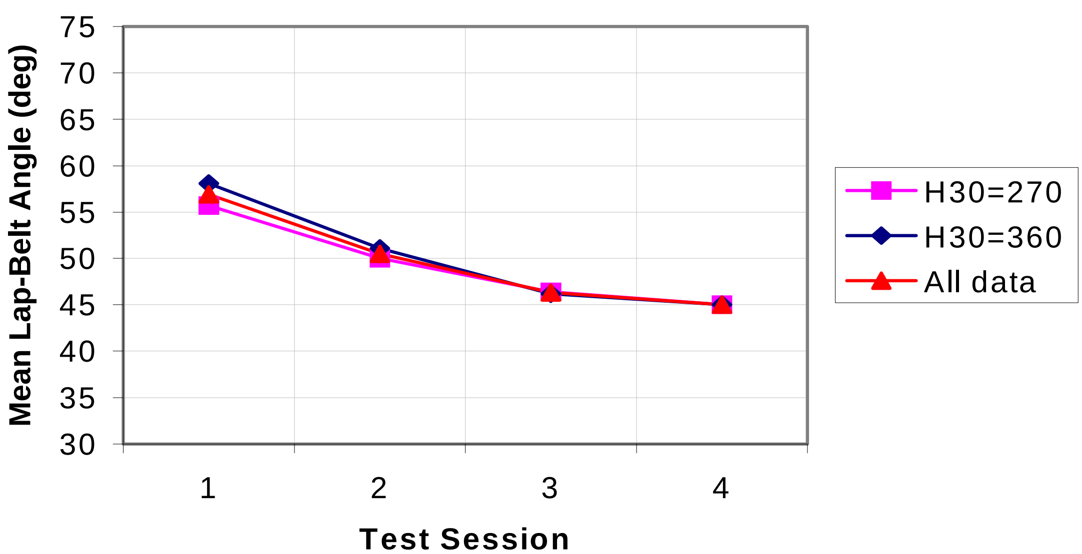


Figure 43. Mean lap-belt angles for all subjects and for each seat height at each test session.

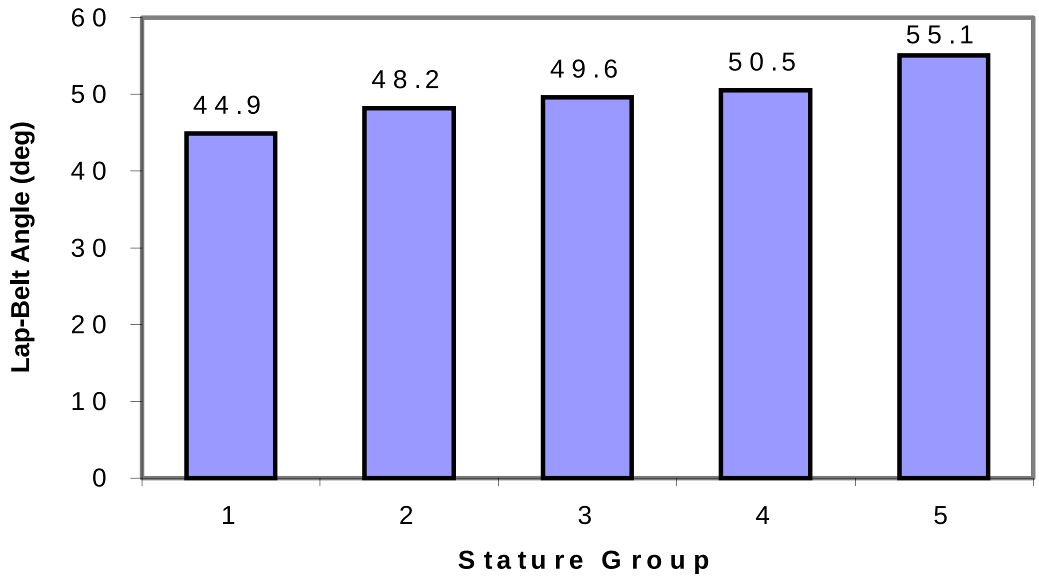


Figure 44. Mean lap-belt angles by stature group.

The mean shoulder-belt angles for each stature group are shown in Figures 45 and 46. The two different shoulder-belt anchorage locations lead to distinctly different actual shoulder-belt angles, which average to 27° and 49° for all subjects ($p<0.0001$) at the 20° and 60° nominal belt-angle locations, respectively. Unlike the lap belt, the actual shoulder-belt angle is only marginally affected by the growing pregnant abdomen ($p=0.06$). The angles are nearly constant with increasing gestational age for all stature groups at both seat heights. Apparently, the increase in shoulder-belt angle that might be expected with shorter stature and sitting height is offset by the more forward seat position of shorter subjects. However, as shown in Figure 47, when the data for all sessions at each nominal shoulder-belt angle were averaged for each stature group, the 60° shoulder-belt angle shows a tendency to increase with stature while the 20° angle remains unchanged. Different lap-belt positions resulted in statistically different shoulder-belt angles for a given nominal shoulder-belt angle, but the differences in angles were less than 1° in all cases. Seat height also had a small but statistically significant effect on shoulder-belt angle.

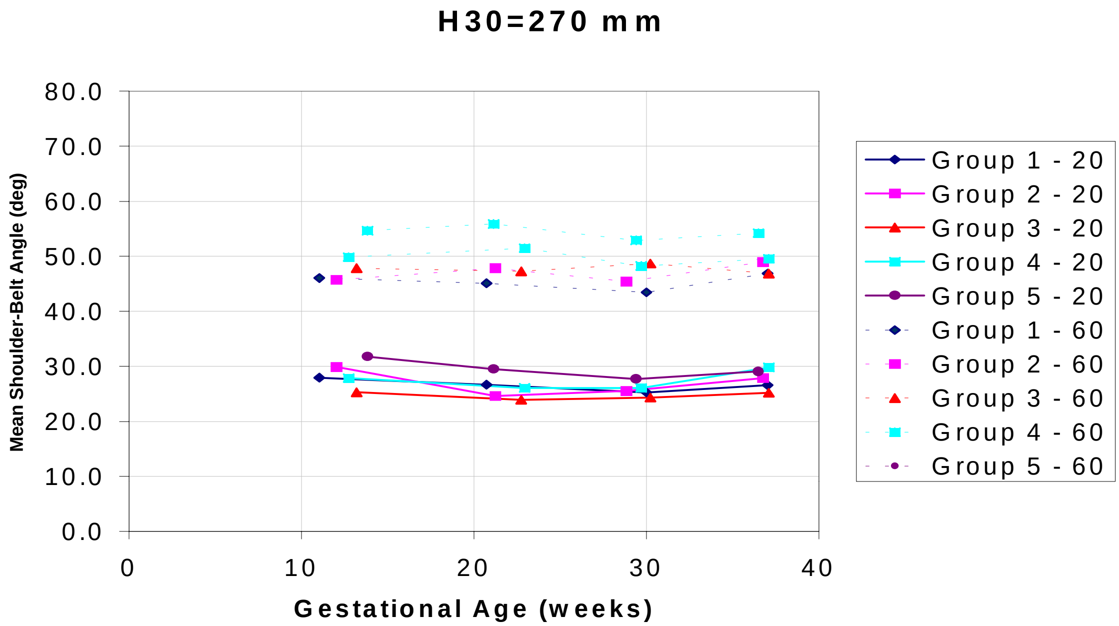


Figure 45. Mean actual shoulder-belt angles by gestational age for each stature group and nominal shoulder-belt anchor condition for the 270-mm seat-height configurations. Dashed lines correspond to the 60° nominal shoulder-belt angle, while solid lines designate the 20° shoulder-belt angle.

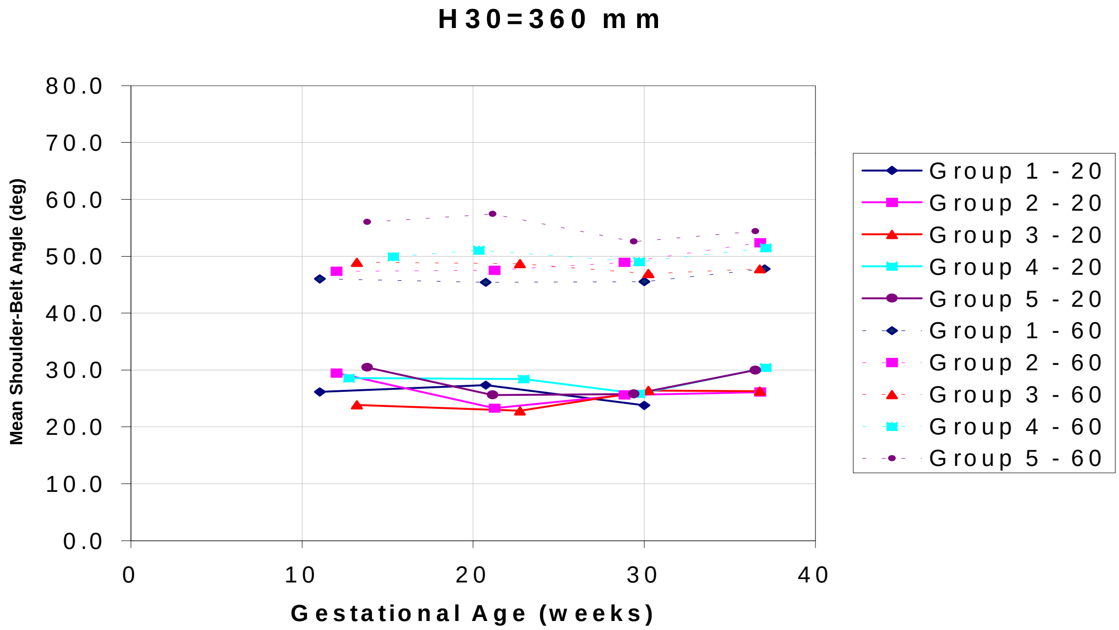


Figure 46. Mean actual shoulder-belt angles by gestational age for each stature group and nominal shoulder-belt anchor condition for the 360-mm seat-height configurations. Dashed lines correspond to the 60° nominal shoulder-belt angle, while solid lines designate the 20° shoulder-belt angle.

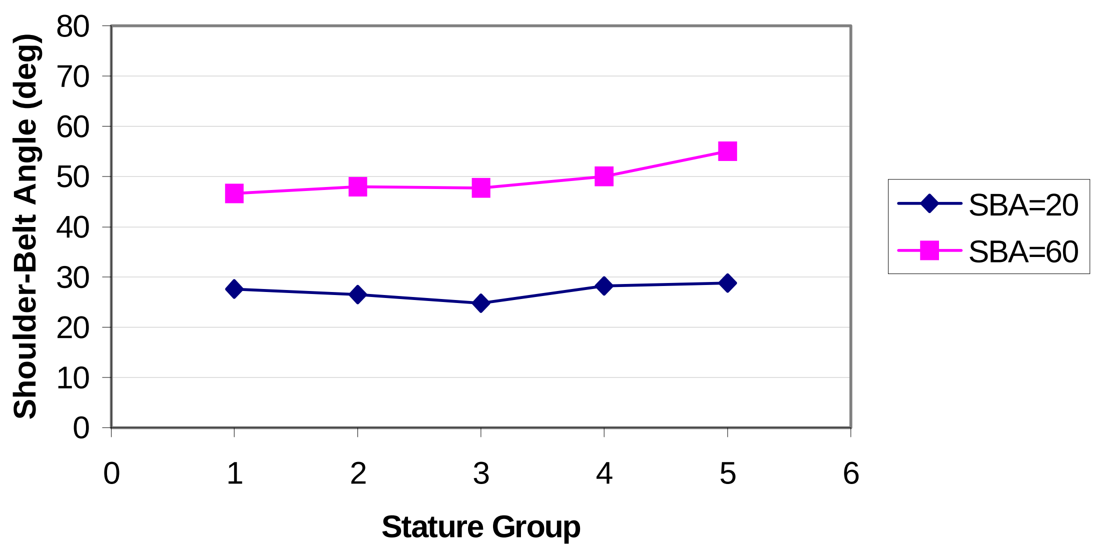


Figure 47. Mean actual shoulder-belt angles by stature group for each nominal shoulder-belt angle.

3.7 Lap-Belt Position

Several other calculations were made in an effort to quantify belt fit, as illustrated in Figure 48. Results are shown in Table 13. For the lap belt, the location of the lap-belt centerline relative to the left and right ASIS points in the vertical direction was calculated. The stature-group mean belt centerline heights are all within +/- 20 mm of the ASIS, with some tendency to be above rather than below the ASIS bony landmarks. No distinct trends with subject stature were found, and no differences were noted for the two nominal lap-belt angles used. The lap belt tended to cross the ASIS at a higher level with the 270-mm seat height (p=0.023 left, p=0.004 right), although the mean difference by seat height is only about 2.5 mm.

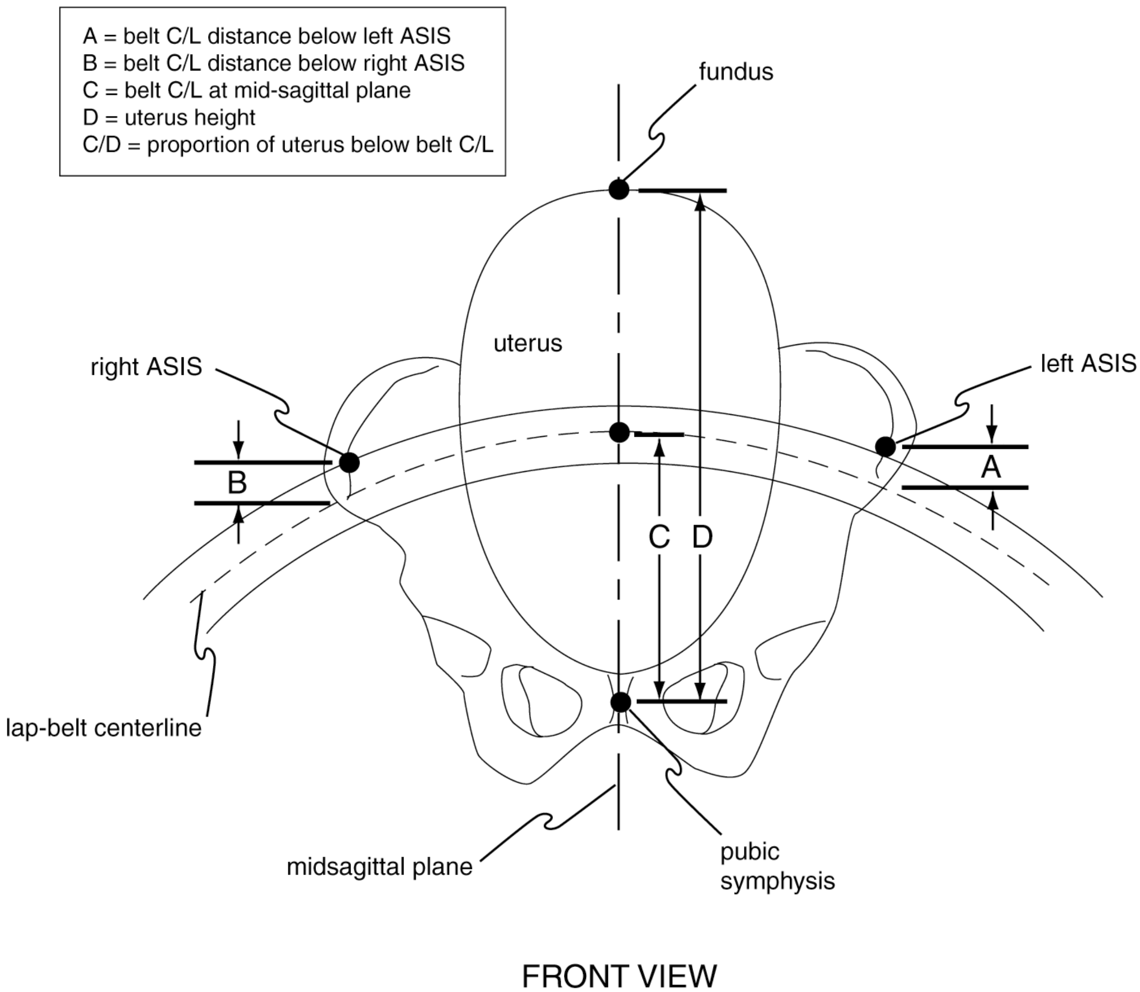


Figure 48. Illustration of lap-belt fit calculations.

Table 13

Mean Vertical Location of Lap-Belt Centerline

Relative to Left ASIS (mm)										
	H30=270 mm, Nominal Lap-Belt Angle=40					H30=270 mm, Nominal Lap-Belt Angle=60				
	Group 1	Group 2	Group 3	Group 4	Group 5	Group 1	Group 2	Group 3	Group 4	Group 5
Session 1	-5.1	4.6	2.8	0.0	0.2	7.2	4.6	2.9	3.6	5.4
Session 2	-10.2	5.0	1.6	-2.1	13.7	-4.8	0.5	1.6	4.8	7.4
Session 3	-8.8	-0.3	0.4	-2.8	3.6	17.3	-4.4	-4.9	6.5	0.0
Session 4	-5.5	-0.2	3.2	3.8	-0.3	11.9	-3.2	0.4	-1.0	0.5
	H30=360 mm, Nominal Lap-Belt Angle=40					H30=360 mm, Nominal Lap-Belt Angle=60				
	Group 1	Group 2	Group 3	Group 4	Group 5	Group 1	Group 2	Group 3	Group 4	Group 5
Session 1	3.8	5.9	1.9	0.2	3.2	-4.4	8.3	3.7	-5.6	2.3
Session 2	-2.1	-2.7	-4.1	9.1	-0.2	-5.2	8.1	-5.7	-1.1	1.7
Session 3	9.2	-2.6	-7.6	-0.9	-1.7	-7.6	0.1	-4.0	-2.0	2.7
Session 4	13.3	-4.9	-10.8	1.9	-6.4	-11.3	-8.0	-4.6	-0.9	-2.3
Relative to Right ASIS (mm)										
	H30=270 mm, Nominal Lap-Belt Angle=40					H30=270 mm, Nominal Lap-Belt Angle=60				
	Group 1	Group 2	Group 3	Group 4	Group 5	Group 1	Group 2	Group 3	Group 4	Group 5
Session 1	-1.9	-0.1	-6.5	-0.1	7.3	13.7	2.8	3.2	5.0	1.2
Session 2	0.5	16.6	0.1	4.1	6.8	8.3	8.9	7.3	8.8	2.2
Session 3	-14.8	9.8	6.5	-2.0	7.3	12.3	3.6	4.7	3.7	3.4
Session 4	-8.6	17.5	0.8	5.2	-2.5	6.2	-1.7	0.5	3.7	0.0
	H30=360 mm, Nominal Lap-Belt Angle=40					H30=360 mm, Nominal Lap-Belt Angle=60				
	Group 1	Group 2	Group 3	Group 4	Group 5	Group 1	Group 2	Group 3	Group 4	Group 5
Session 1	11.1	6.4	-4.5	-0.8	-1.5	-1.0	0.3	-2.4	3.8	5.9
Session 2	15.3	-1.6	-2.0	5.1	-0.5	-2.2	9.6	-5.9	-0.5	4.1
Session 3	-3.7	-1.0	4.4	1.4	3.0	-6.7	1.8	-4.9	-2.2	4.1
Session 4	-3.3	-8.4	-0.2	6.5	-3.6	1.0	6.7	-0.6	1.8	8.4
	Relative to Uterus at Midsagittal Plane (%)									
	H30=270 mm, Lap-Belt Angle=40					H30=270 mm, Lap-Belt Angle=60				
	Group 1	Group 2	Group 3	Group 4	Group 5	Group 1	Group 2	Group 3	Group 4	Group 5
Session 2	0.67	0.50	0.58	0.66	0.70	0.62	0.47	0.58	0.58	0.53
Session 3	0.55	0.67	0.54	0.64	0.70	0.79	0.57	0.53	0.53	0.53
Session 4	0.62	0.60	0.54	0.67	0.72	0.83	0.54	0.61	0.61	0.52
	H30=360 mm, Lap-Belt Angle=40					H30=360 mm, Lap-Belt Angle=60				
	Group 1	Group 2	Group 3	Group 4	Group 5	Group 1	Group 2	Group 3	Group 4	Group 5
Session 2	0.71	0.49	0.55	0.60	0.52	0.69	0.52	0.47	0.63	0.65
Session 3	0.75	0.52	0.56	0.56	0.51	0.54	0.63	0.53	0.59	0.64
Session 4	0.81	0.53	0.56	0.55	0.53	0.62	0.57	0.50	0.68	0.77

Notes: H30 = vehicle seat height
Negative values indicate belt centerline is below ASIS
Positive values indicate belt centerline is above ASIS

Also shown in Figure 48 is another variable that was calculated to describe the level at which the lap-belt centerline crossed the midline of the pregnant uterus. The height of the uterus is defined by the vertical distance between the fundus and pubic symphysis. The lap-belt crossing height was calculated by subtracting the z coordinate of the pubic symphysis from the z coordinate of the lap-belt centerline where it crossed the midline of the abdomen. The ratio of the belt crossing height to the uterus height indicates the fraction of the uterus that is below the lap-belt centerline in the midsagittal plane. Negative values indicate that the uterus lies completely below the lap belt and were set to zero. The mean values of this ratio for each stature group and test session are shown in Table 13. As noted previously, the fundal location was not measured until the second test session, so this variable was not calculated for the first test session.

For all groups, between 50% and 80% of the uterus lies below the lap-belt centerline, and the values show no statistically significant variation with gestational age. Although the uterus height increases with gestational age, the position of the lap belt also changes, leading to unexpectedly consistent values throughout the course of pregnancy. These ratios occurred with the lap-belt centerline crossing fairly close to the ASIS. They suggest that correct positioning of the belt over or below the ASIS still allows loading of the uterus at the midline, which protrudes significantly forward of the ASIS in the latter stages of pregnancy.

3.8 Shoulder-Belt Position

Three variables were calculated to describe the location of the shoulder belt on the subject, as illustrated in Figure 49. All are expressed as ratios of where the shoulder-belt centerline crossed a body component relative to the length of the body component. The sternum, clavicle, and shoulder are the body components used. For example, a ratio of zero corresponds to the shoulder-belt centerline crossing the bottom of the sternum, the sternoclavicular joint, or the neck/shoulder junction, respectively. A ratio of 50% corresponds to the shoulder-belt centerline crossing the midpoints of these components.

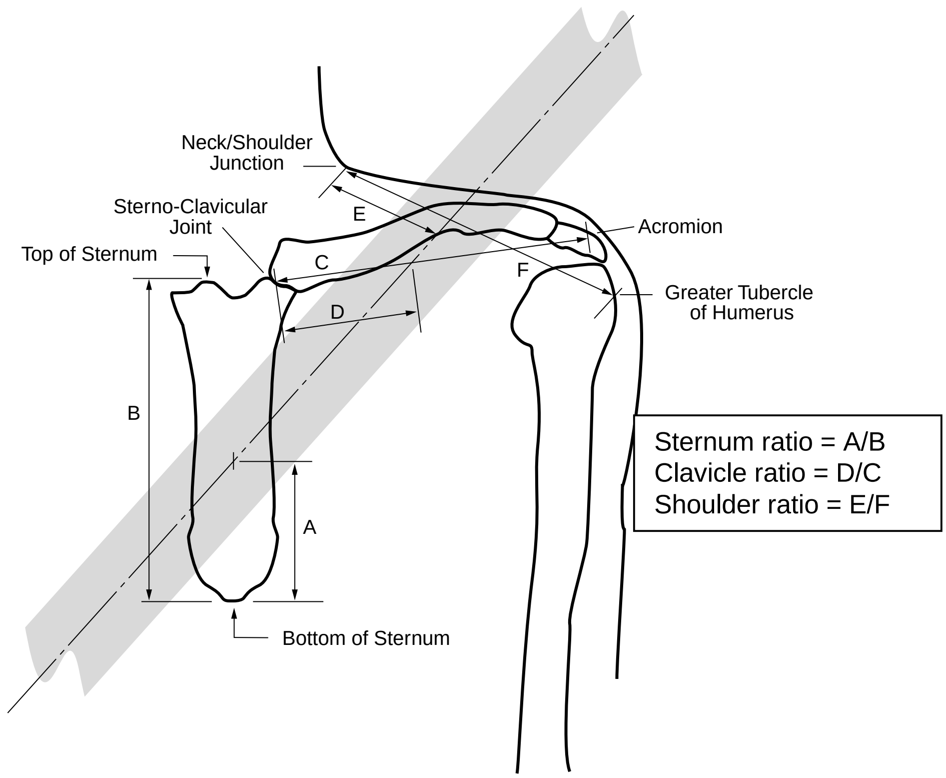


Figure 49. Illustration of shoulder-belt crossing ratios.

Figures 50 and 51 illustrate the mean ratios describing where the shoulder belt crossed the sternum for each stature group and nominal shoulder-belt angle. Figure 52 shows the average values at each seat for all subjects at each test session. Higher ratios indicate higher belt position on the sternum. The shoulder-belt centerline crossed near the midpoint of the sternum, with the crossing ratio increasing somewhat with gestational age ($p<0.0001$). A more distinct increase in ratio occurs between the third and fourth test sessions. The nominal 60° shoulder-belt angle routes the shoulder belt higher over the sternum ($p=0.002$), with the differences most evident in the third and fourth test sessions ($p=0.006$).

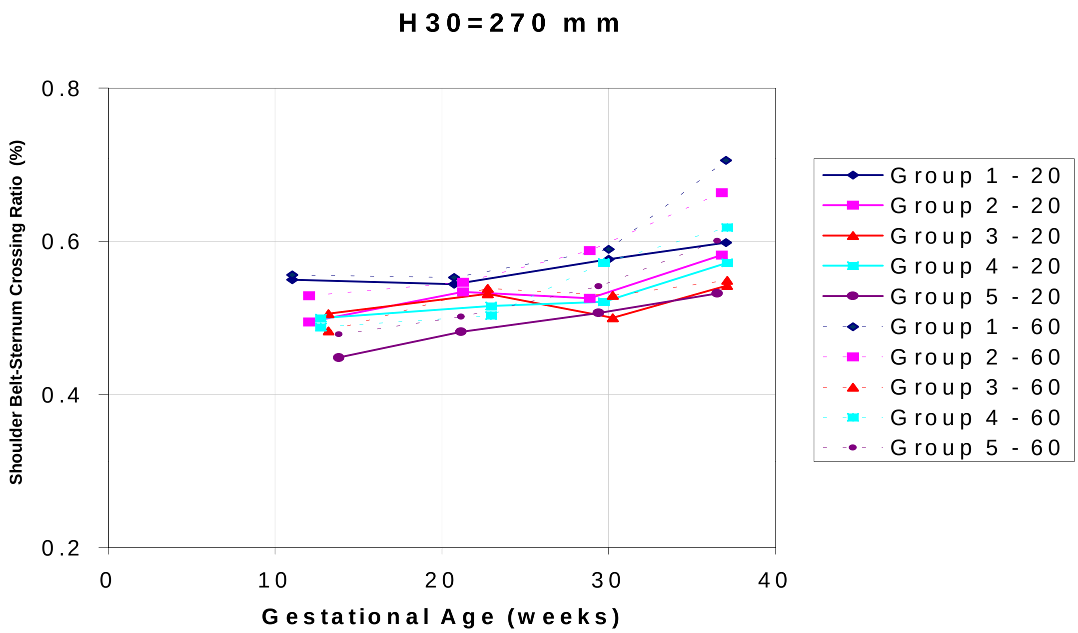


Figure 50. Ratio of shoulder-belt crossing on sternum by gestational age for 270-mm seat-height configurations. Dashed lines correspond to the 60° nominal shoulder-belt angle, while solid lines designate the 20° shoulder-belt angle.

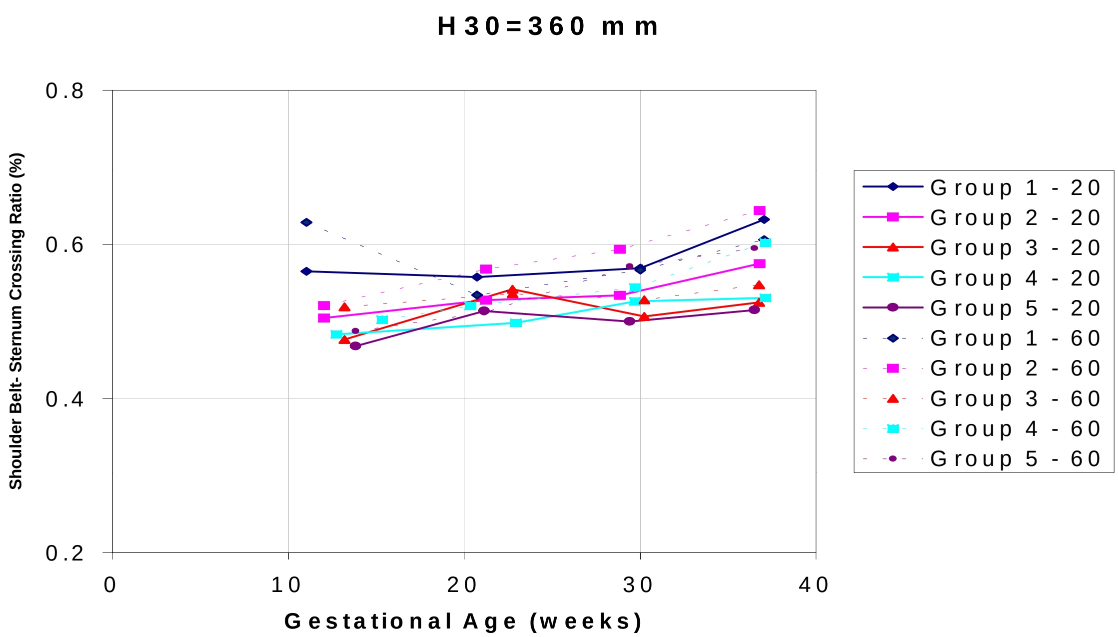


Figure 51. Ratio of shoulder-belt crossing on sternum by gestational age for 360-mm seat-height configurations. Dashed lines correspond to the 60° nominal shoulder-belt angle, while solid lines designate the 20° shoulder-belt angle.

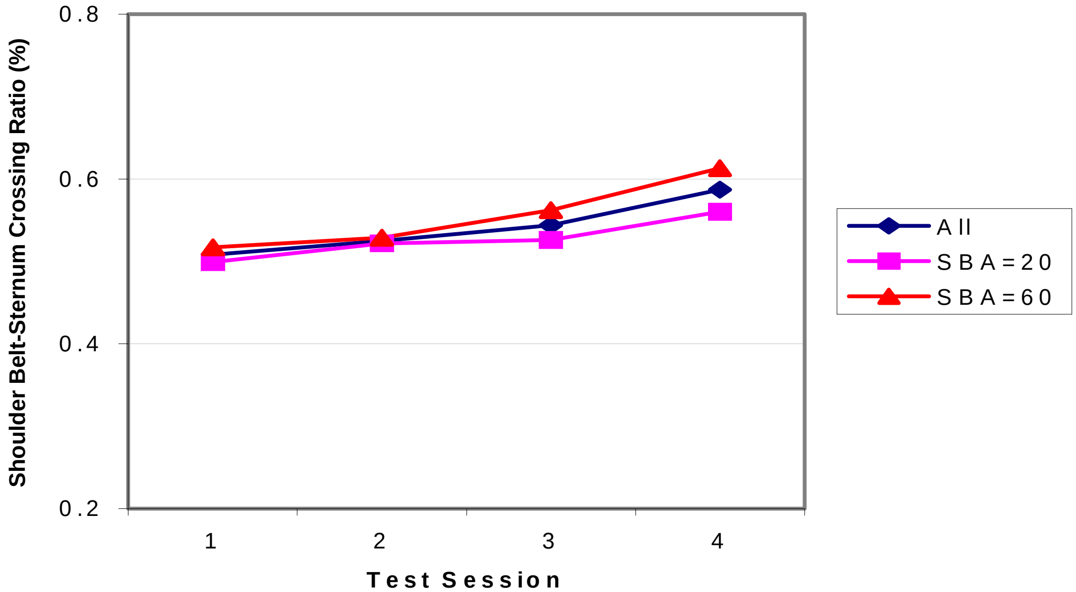


Figure 52. Ratio of shoulder-belt crossing on sternum for each test session and nominal shoulder-belt angle (SBA).

Figures 53 and 54 show the mean ratios of shoulder-belt crossing on the clavicle by gestational age for each stature group and nominal shoulder-belt angle. Figure 55 shows the average of all points at each test session. These ratios decrease with gestational age (p=0.002), which means that the shoulder belt shifts closer toward the middle of the body. For both seat heights and all stature groups, the 20° nominal belt angle resulted in the belt being closer to the center point of the clavicle (p<0.0001).

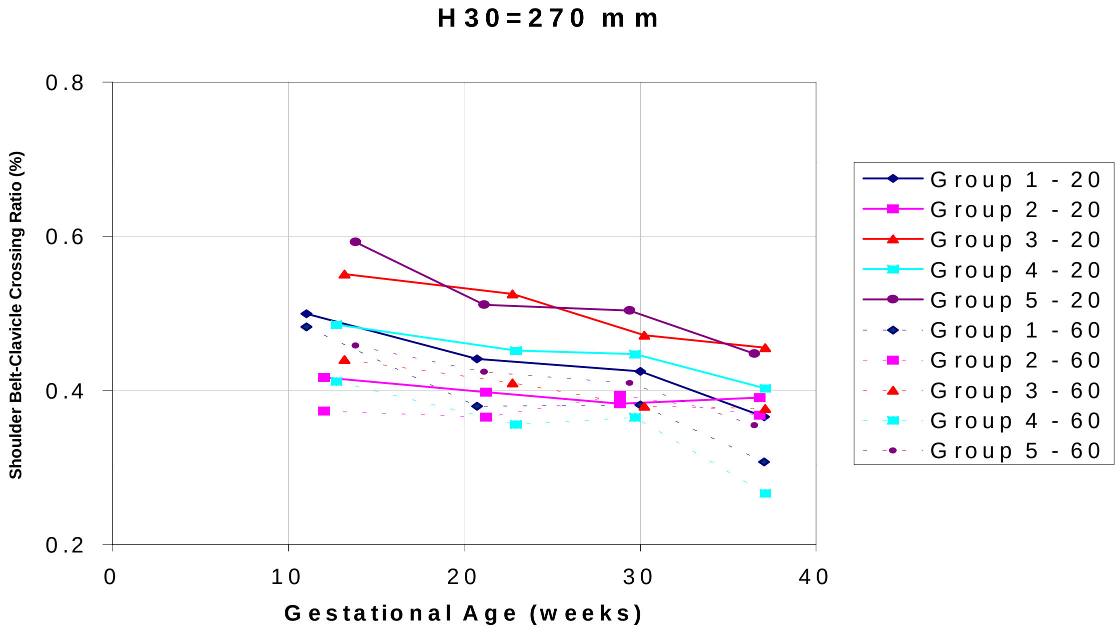


Figure 53. Ratio of shoulder-belt crossing on clavicle by gestational age for 270-mm seat-height configurations. Dashed lines correspond to the 60° nominal shoulder-belt angle, while solid lines designate the 20° shoulder-belt angle.

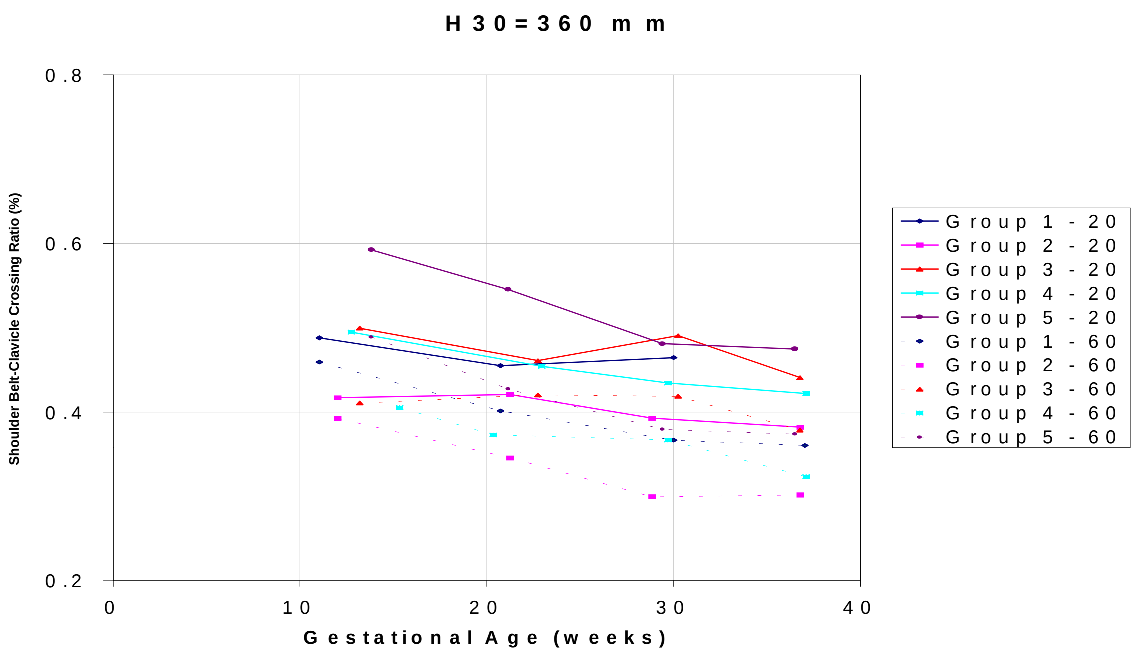


Figure 54. Ratio of shoulder-belt crossing on clavicle by gestational age for 360-mm seat-height configurations. Dashed lines correspond to the 60° nominal shoulder-belt angle, while solid lines designate the 20° shoulder-belt angle.

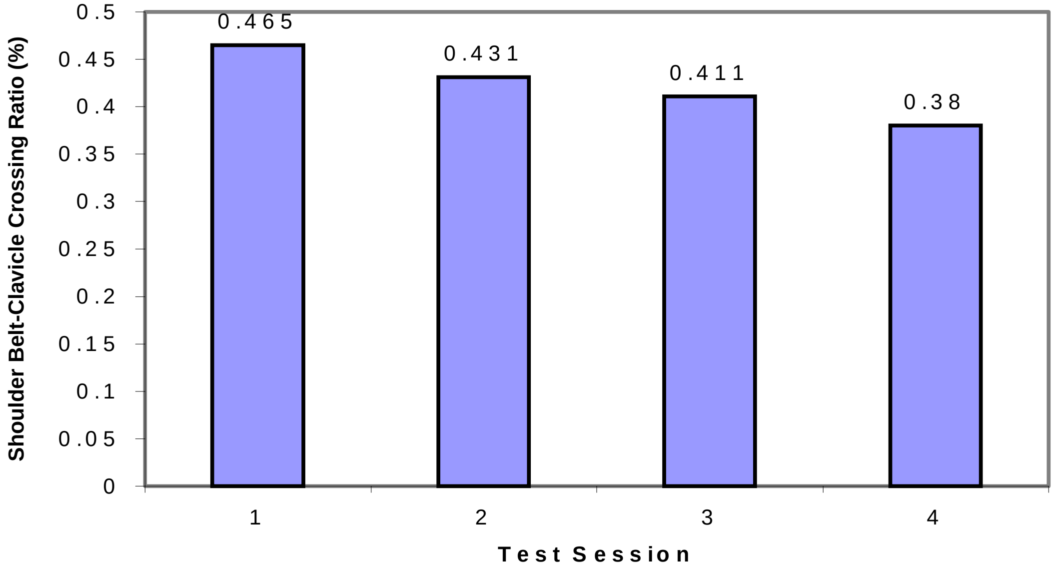


Figure 55. Ratio of shoulder-belt crossing on clavicle by test session for all stature groups and test configurations.

Figures 56 and 57 show the mean ratios of shoulder-belt crossing on the shoulder for each seat height, stature group, and nominal belt angle. In all cases, the centerline of the shoulder belt crosses the shoulder at about one-third of the distance between the neck/shoulder junction and the left greater tubercle of the humerus.

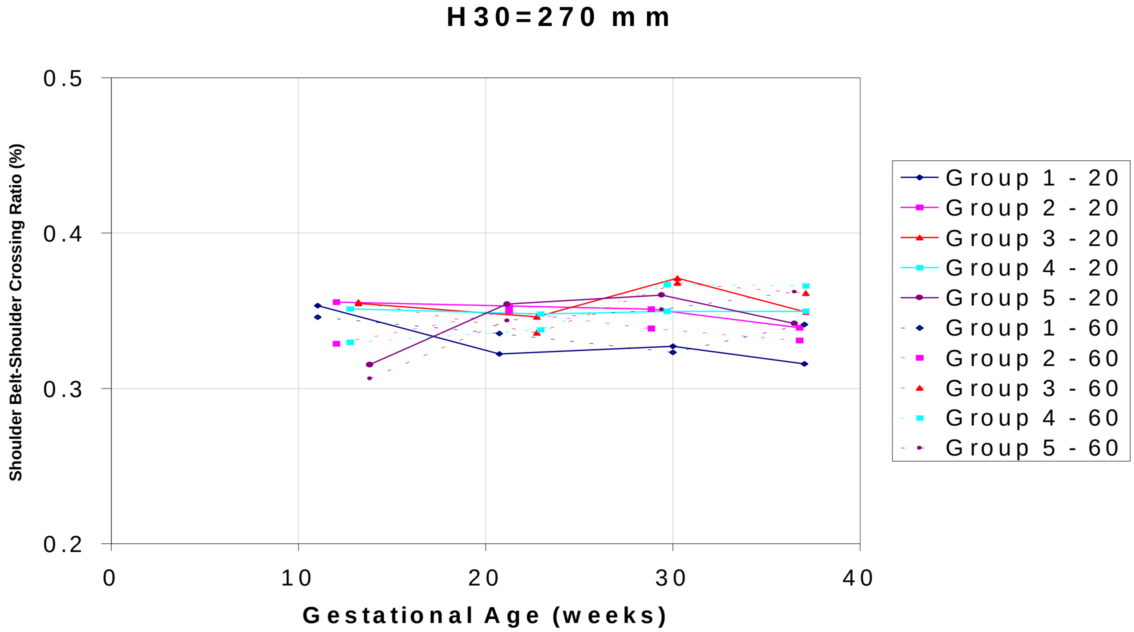


Figure 56. Ratio of shoulder-belt crossing on shoulder by gestational age for 270-mm seat-height configurations. Dashed lines correspond to the 60° nominal shoulder-belt angle, while solid lines designate the 20° shoulder-belt angle.

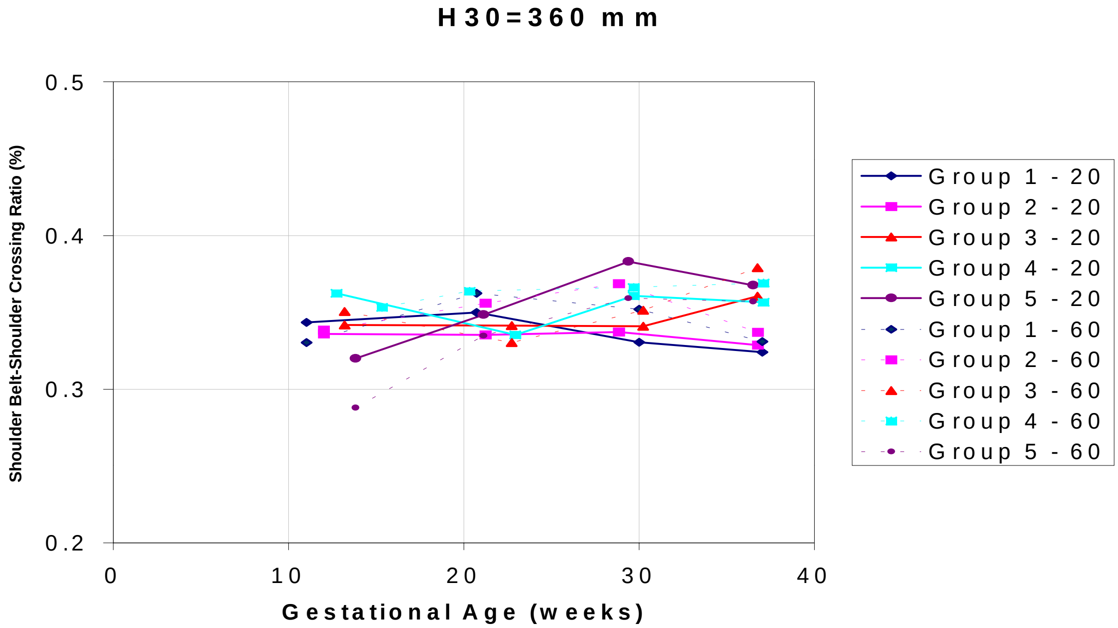


Figure 57. Ratio of shoulder-belt crossing on shoulder by gestational age for 360-mm seat-height configurations. Dashed lines correspond to the 60° nominal shoulder-belt angle, while solid lines designate the 20° shoulder-belt angle.

3.9 Belt-Fit Illustrations

In addition to these quantitative measures of belt fit, qualitative information about belt fit is available from subject photographs and three-dimensional graphical reconstructions. Appendix H contains photos of one subject from each stature group at all four test sessions for two configurations that represent examples of each seat height, shoulder-belt angle, and lap-belt angle. For each subject, differences in shoulder belt position can be seen for the 20° and 60° anchorage locations, but not for changes in gestation. However, the lap belt-angle becomes shallower with increasing gestational age, and is also lower for the 40° belt anchorage location.

Figure 58 shows close-up photographs of shoulder-belt routing on a Group-4 statured subject in the last three test sessions. The higher location of the shoulder belt across the neck for the 60° anchorage location is readily seen. In addition, the shoulder belt does not lie as flat as it passes over the chest later in pregnancy for either belt configuration.

Figure 58a. Test session 2, shoulder belt 20°, lap belt 40°.

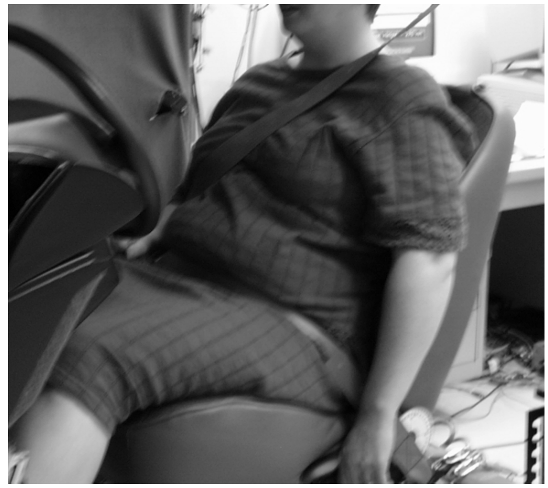


Figure 58b. Test session 2, shoulder belt 60°, lap belt 60°.

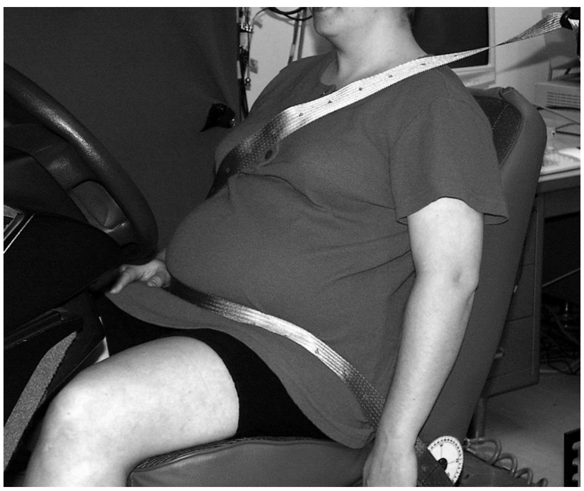


Figure 58c. Test session 3, shoulder belt 20°, lap belt 60°.

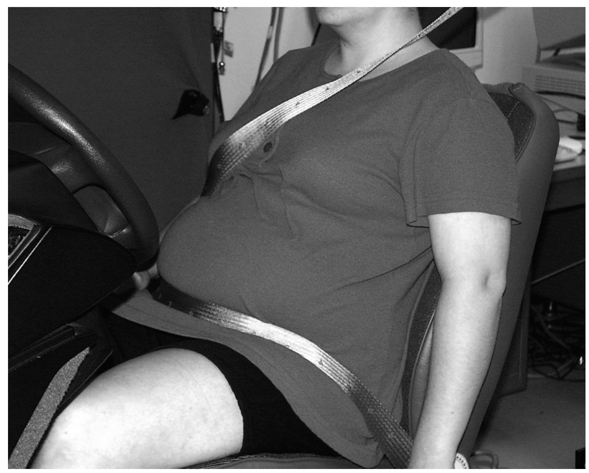


Figure 58d. Test session 3, shoulder belt 60°, lap belt 60°.

Figure 58e. Test session 4, shoulder belt 20°, lap belt 60°.

Figure 58f. Test session 4, shoulder belt 60°, lap belt 40°.

Figures 59 and 60 are computer model reconstructions of a Group-2 subject and her belt position. These figures were generated using Transom Jack human simulation software. The standard female Jack model was scaled to match the size of the subject. For this subject, surface contours of the pregnant abdomen were available for each test session, so they were processed to create a surface and combined with the scaled female. Representations of the buck components were imported, as were the coordinates of the belts. The human model was positioned in the buck and adjusted to a realistic position relative to the belts. The scaled female does not have the same surface contours as the subject (except for the pregnant abdomen), so the drawing is not exact. However, it gives an idea in three dimensions how the belt fit changes throughout pregnancy for two different shoulder-belt configurations. As calculated earlier, both belts appear to cross higher over the sternum and become closer to the neck later in pregnancy. Viewing the belts from this angle also shows how the curve of the shoulder belt changes later in pregnancy to go around the pregnant abdomen. The change in shape of the lap belt with gestation is also visible.

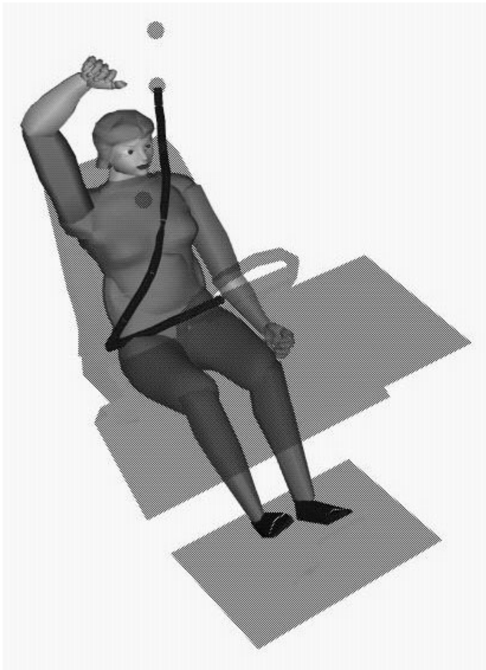


Figure 59a. Visit 1, shoulder belt 20°.

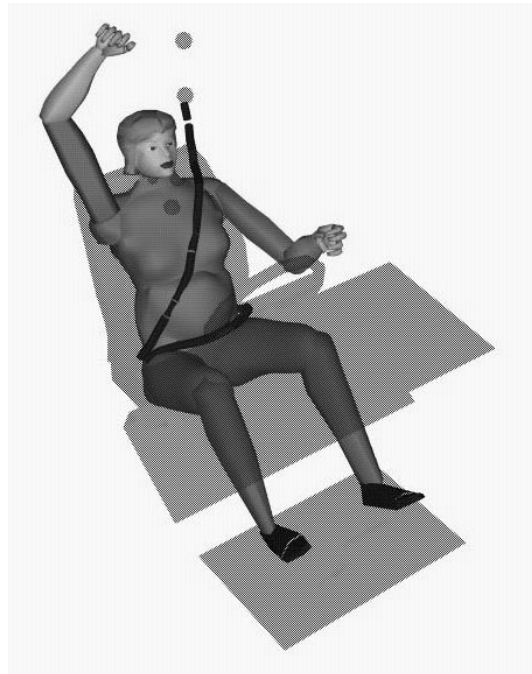


Figure 59b. Visit 2, shoulder belt 20°.

Figure 59c. Visit 3, shoulder belt 20°.

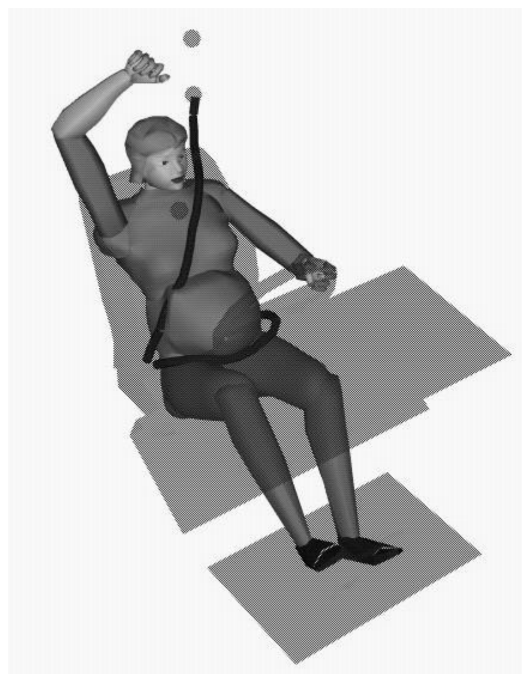


Figure 59d. Visit 4, shoulder belt 20°.

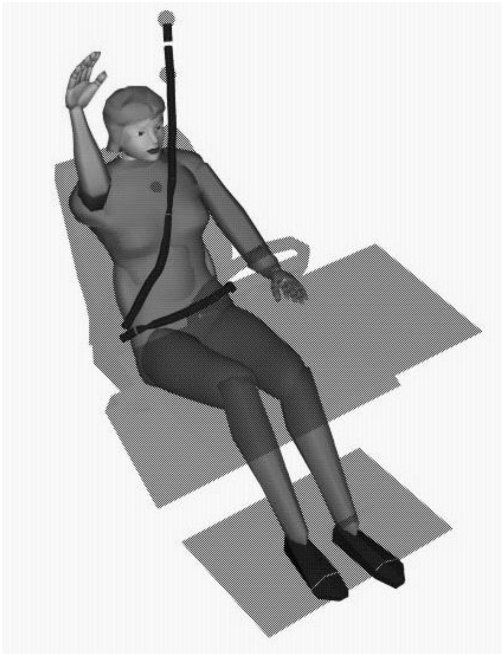


Figure 60a. Visit 1, shoulder belt 60°.

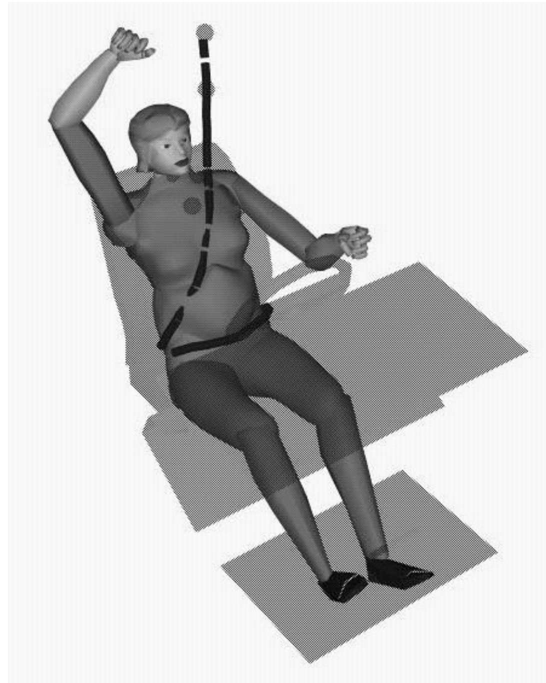


Figure 60b. Visit 2, shoulder belt 60°.

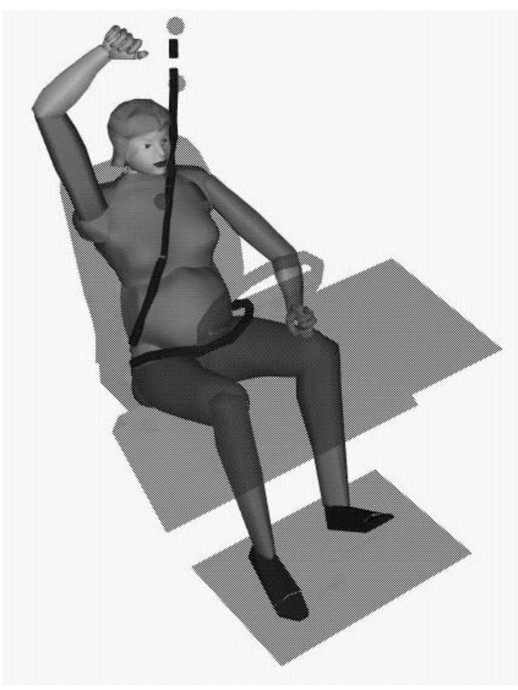


Figure 60c. Visit 3, shoulder belt 60°.

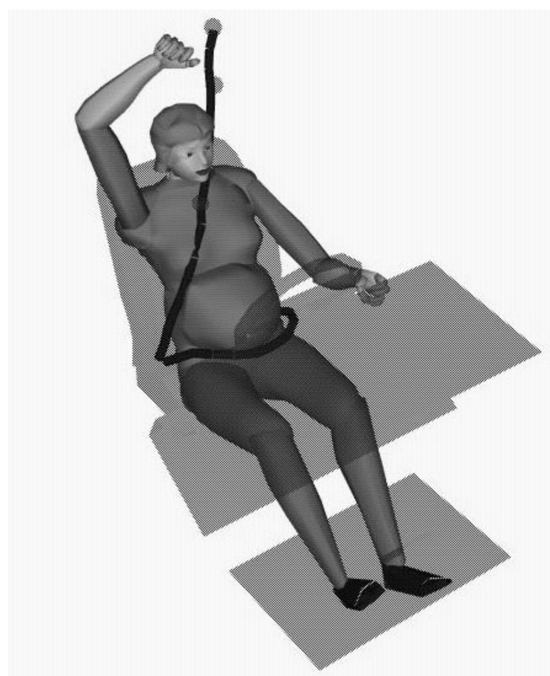


Figure 60d. Visit 4, shoulder belt 60°.

3.10 Subject Comments on Test Conditions

After completing posture measurements in each test session, subjects were asked to evaluate their accommodation to the package and restraint geometry by answering the questions on the first questionnaire in Appendix D. These evaluations are typically used in seating studies to determine if subjects were able to achieve a satisfactory driving posture. Frequency histograms for all test conditions are provided in Figures 61 to 72.

When asked to describe their satisfaction with the steering-wheel fore/aft location, most of the subjects answered that it was "just right" (Figure 61). However, the response varies somewhat with gestational age (p=0.046), with more subjects answering that the steering-wheel was somewhat too close at each successive test session. As shown in Figure 62, the majority of subjects found the steering-wheel tilt angle acceptable throughout their pregnancy; this was true regardless of subject stature or test configuration.

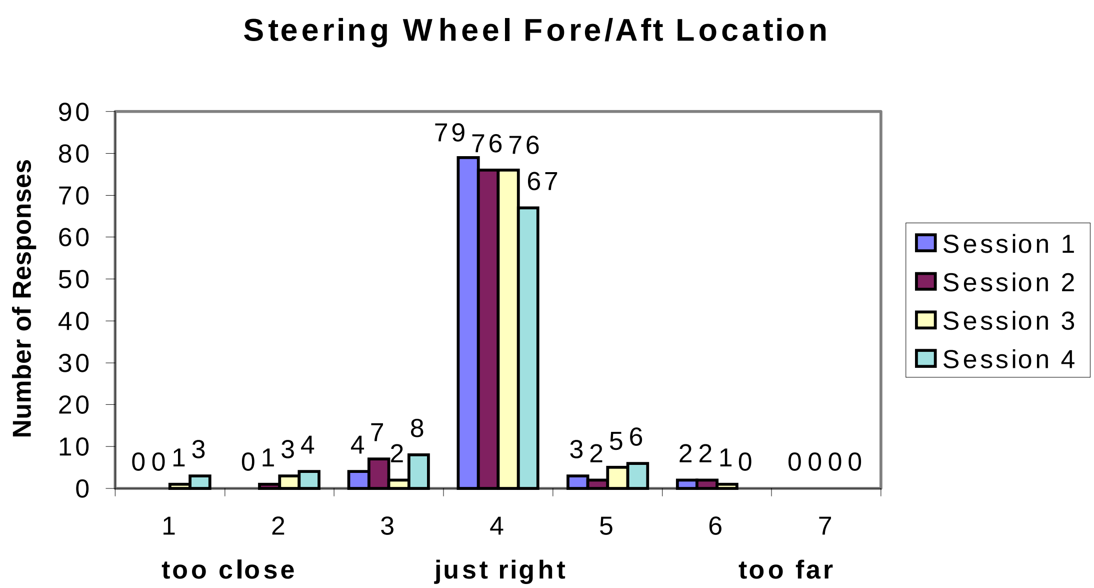


Figure 61. Histogram of subject comments on steering-wheel fore/aft location by test session.

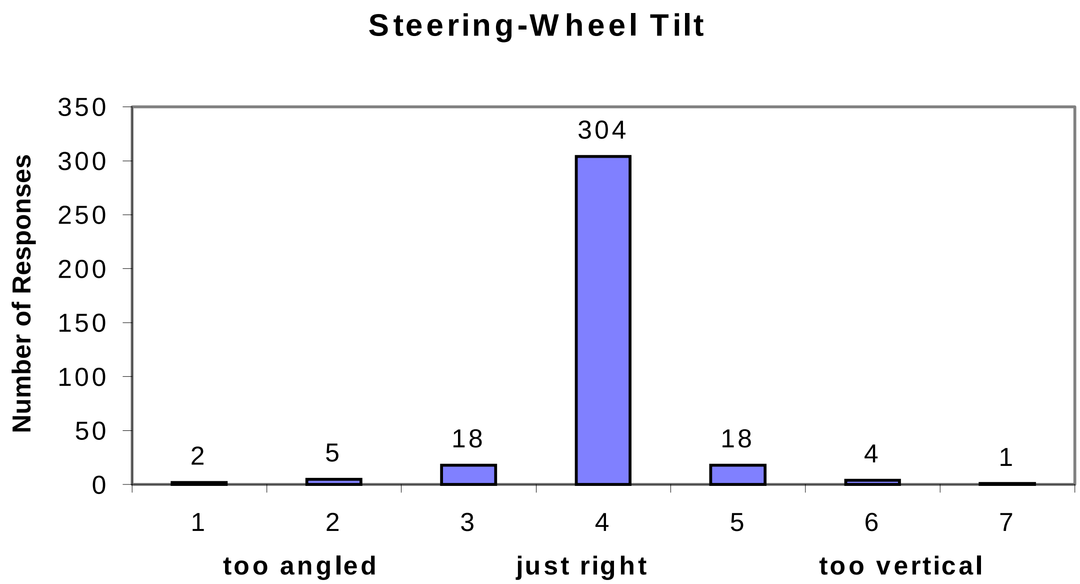


Figure 62. Histogram of subject comments on steering-wheel tilt.

Satisfaction with pedal fore/aft location was independent of gestational age, subject stature, and test configuration. As shown in Figure 63, most subjects were content with the pedal fore/aft location, with a few answering that they were slightly too far away. As shown in Figures 64 and 65, most subjects considered their abdomen and leg clearance acceptable regardless; responses did not vary with gestational age, stature group, or test configuration.

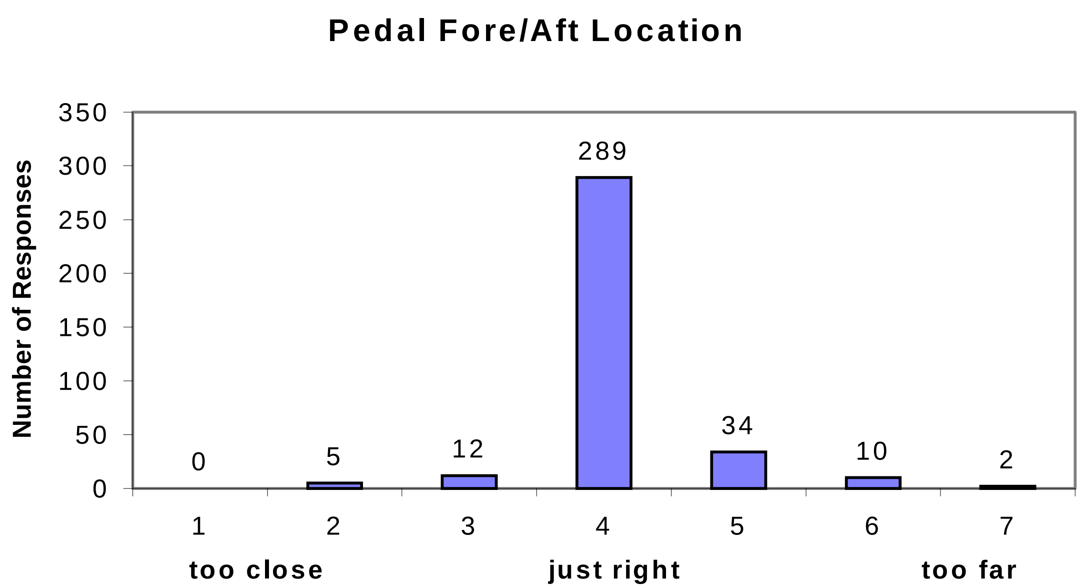


Figure 63. Histogram of subject comments on pedal fore/aft location.

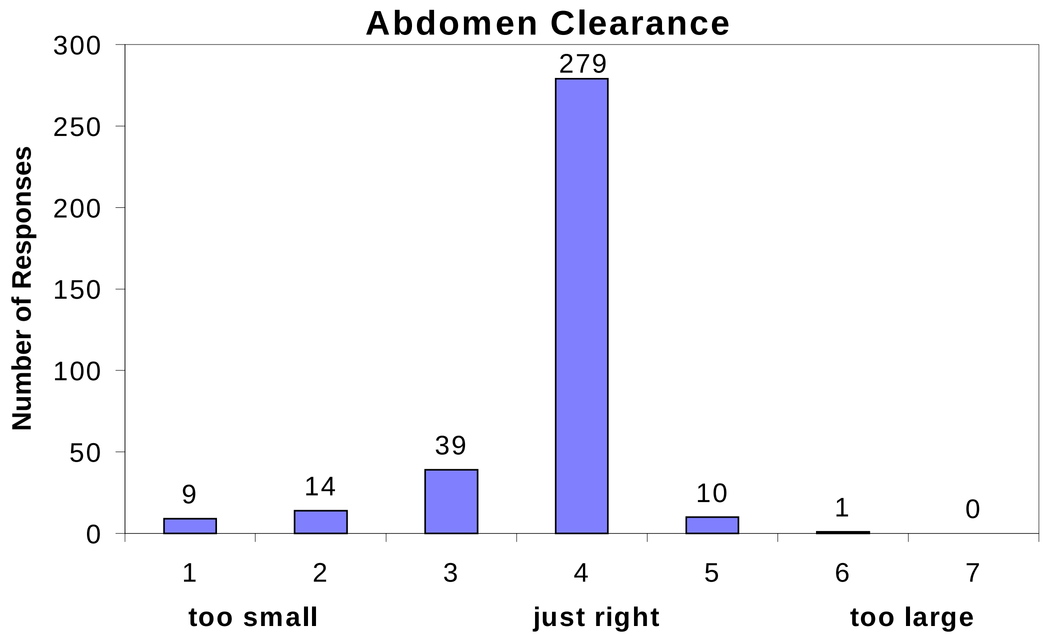


Figure 64. Histogram of subject comments on abdomen clearance.

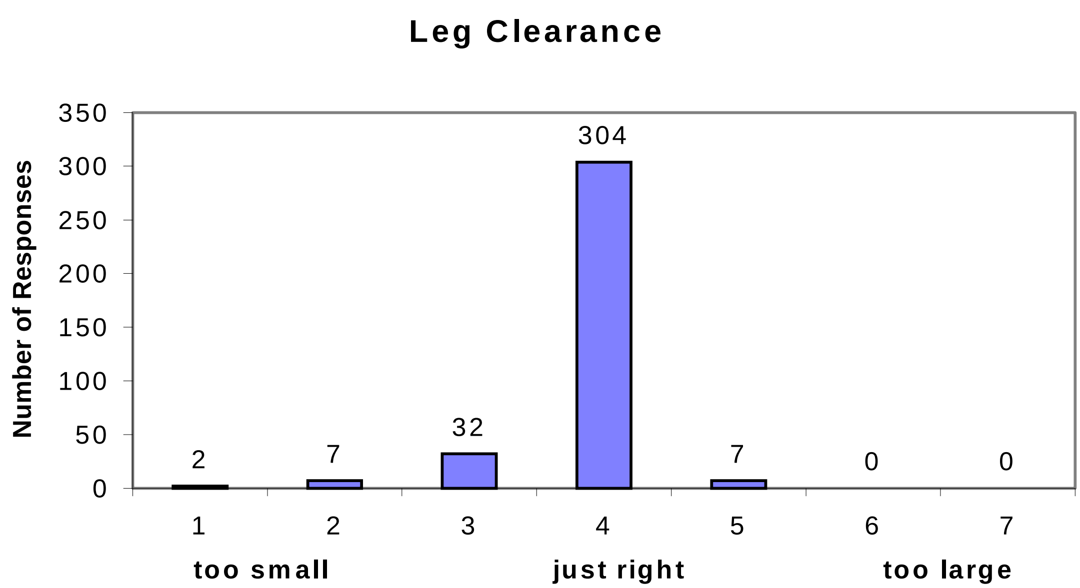


Figure 65. Histogram of subject comments on leg clearance.

As shown in Figure 66, ratings of seatback angle varied with stature. To allow better graphical comparison, Groups 1 and 2 were normalized to have the same number of responses as the other three stature groups. Most subjects in all stature groups were comfortable with their selected seatback angle, but Group-1 subjects more often indicated that the seatback angle was too reclined (p=0.005). Seatback angle responses were independent of gestational age and test configuration.

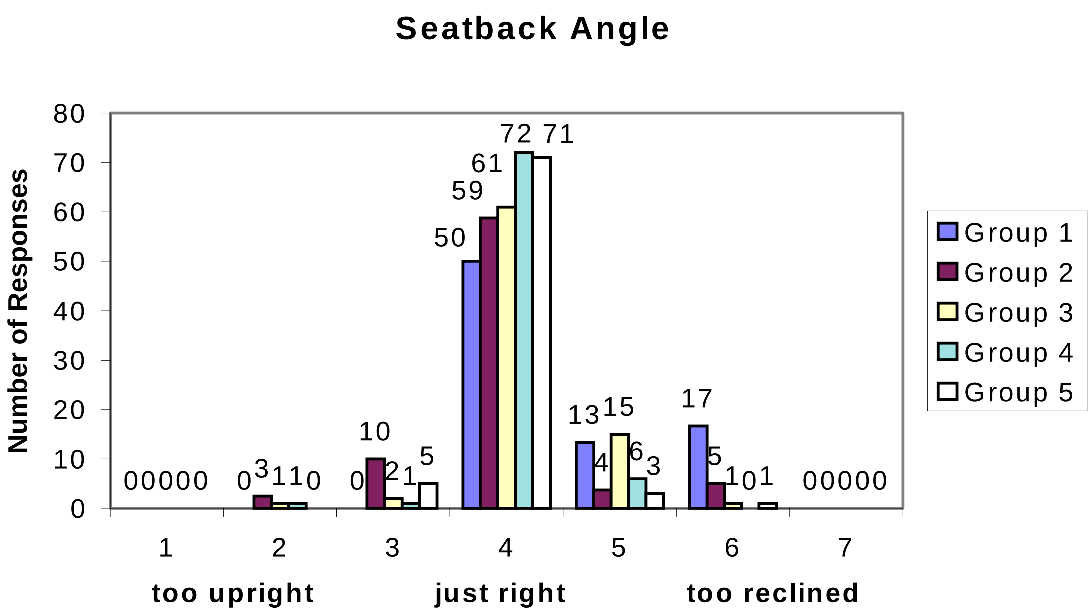


Figure 66. Histogram of subject comments on seatback angle by stature group.

As shown in Figure 67, the majority of subjects commented that the seat-cushion angle (set to 14.5° for all test configurations) was adequate. The configurations with seat height set to 360 mm resulted in more subjects indicating that the cushion angle was too high in front (p=0.043). For cushion length, shown in Figure 68, most subjects thought the length was satisfactory, with a slight tendency to consider it too short, particularly with the H30=270 mm configurations (p=0.019). Satisfaction with cushion angle or cushion length did not depend on gestational age or subject stature.

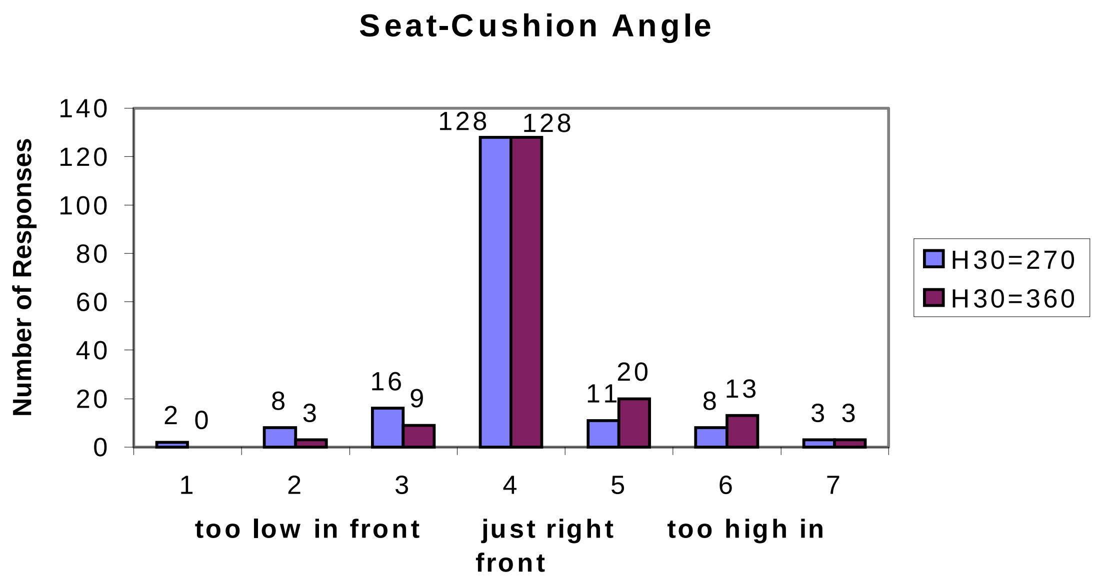


Figure 67. Histogram of subject comments on seat-cushion angle.

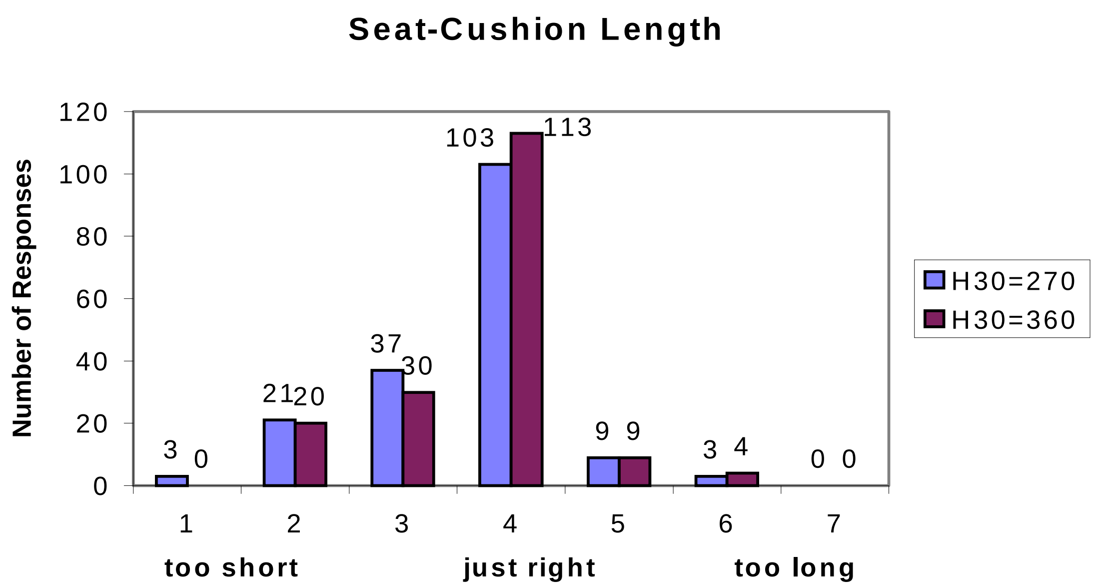


Figure 68. Histogram of subject comments on seat-cushion length.

As expected and shown in Figure 69, when asked if they compromised their ideal seat position because of their pregnancy, the number of subjects responding "yes" increased with gestational age ($p=0.002$). At the last test session, more than half of the responses indicated that their pregnancy was affecting their preferred seating position. Interestingly, responses were independent of subject stature or test configuration, even though large differences in the amount of abdomen-to-wheel clearance for each stature group were present, as shown in Figures 27 and 28.

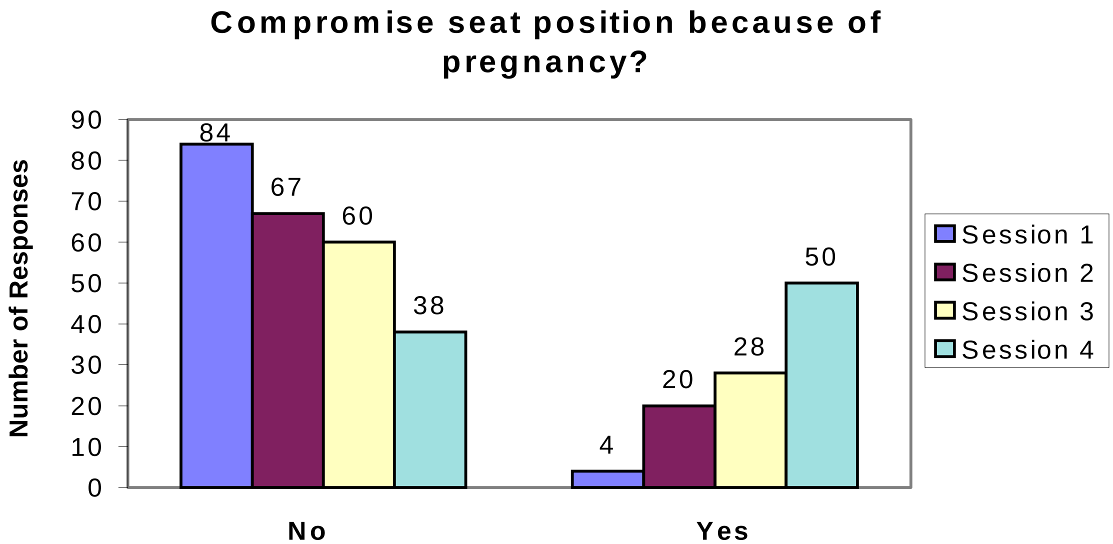


Figure 69. Histogram of subject comments on whether they compromised their seat position because of pregnancy by test session.

Figure 70 shows that after the first test session, the majority of subjects said they compromised their lap-belt position from their preferred position (p=0.051). This suggests that they do not try to keep the lap belt low over the pelvis when they are not pregnant, even though it is the recommended placement for all occupants to avoid injury to the soft abdominal tissues.

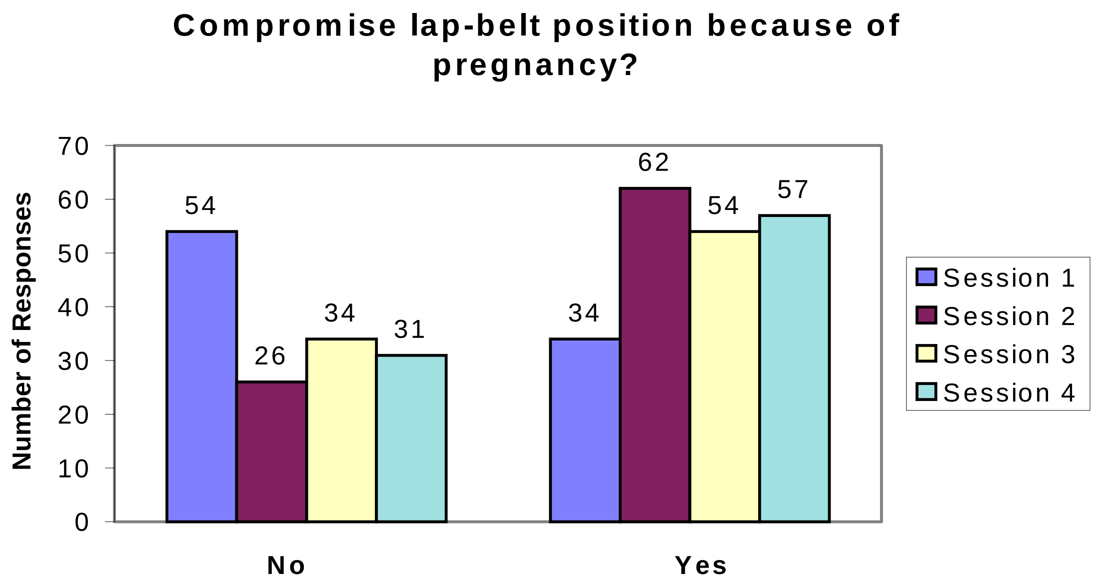


Figure 70. Histogram of subject comments on whether they compromised their lap-belt position because of pregnancy by test session.

Regarding shoulder-belt fit, shown in Figure 71, the majority of responses indicated that it was adequate, although several responses described the shoulder belt as being too close to the neck. Figure 72 indicates that most subjects said they did not compromise their preferred shoulder belt position as a result of their pregnancy. The responses to both questions regarding shoulder-belt fit were independent of gestational age, stature group, or test configuration.

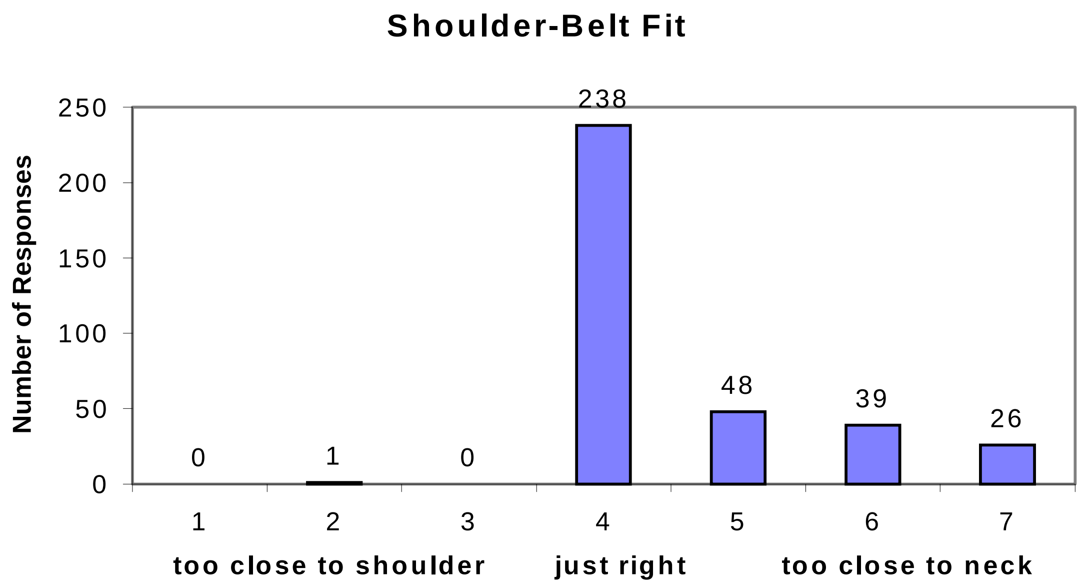


Figure 71. Histogram of subject comments on shoulder-belt fit.

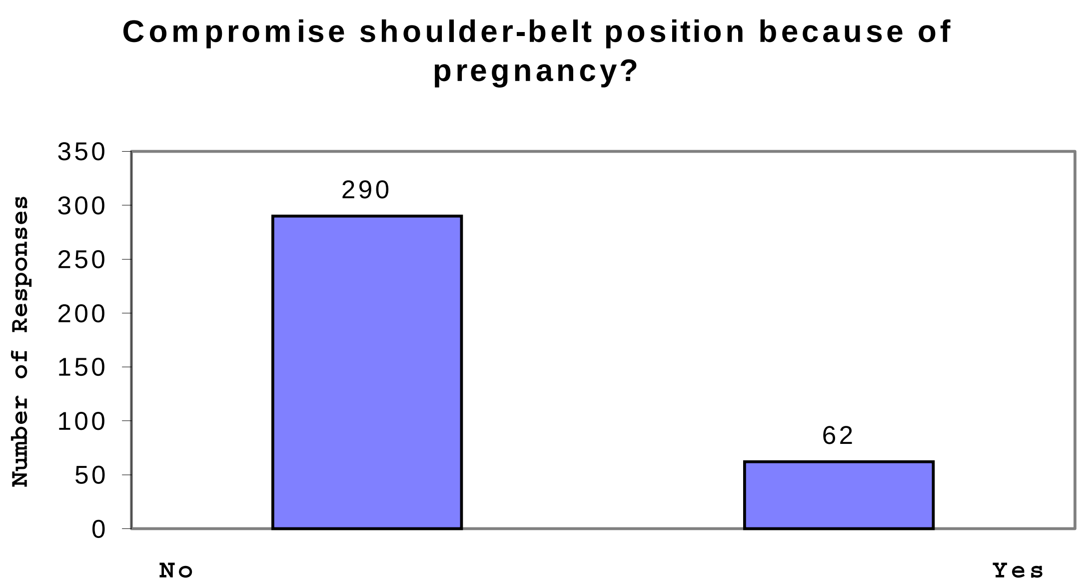


Figure 72. Histogram of subject comments on whether they compromised shoulder-belt position because of pregnancy.

3.11 Subject Comments on Experiences in Their Own Vehicles

Subjects were also asked about their posture and belt fit in their own vehicles at the end of each test session using the second questionnaire in Appendix D. The purpose of these questions was to determine if the pregnant subjects had similar experiences in their own vehicles as they did in the laboratory seating buck. Although numerical analysis of their descriptive comments is not possible, some of the more common responses are expressed as a percentage of the total number of times the question was asked (22 subjects x 4 test sessions = 88).

When asked if they adjusted their fore/aft seating position in their own vehicles to accommodate their pregnant abdomen since the previous test session, subjects responded about 20% of the time that they moved rearward, with half of these responses at the fourth test session. One Group-3 subject said that she moved forward on both the third and fourth test sessions because she reclined the seatback more.

Subjects adjusted their seatback angle during pregnancy for a variety of reasons, including to avoid heartburn, to prevent back or tailbone pain, to improve shoulder-belt fit, to prevent dizziness, and to allow fit between the seatback and the steering wheel. Of subjects who adjusted their seatback, those in Groups 1 to 4 said they reclined more, with more subjects reporting this adjustment at successive test sessions. However, most Group-5 subjects who adjusted their seatback angle said they sat more upright. Three subjects said they used the lumbar adjustment more now that they were pregnant.

Subjects reported adjusting steering-wheel tilt in their own vehicles because of their pregnancies 11% of the times they were asked this question. All reported moving the steering wheel to a more horizontal orientation.

Subjects indicated that they adjusted the lap belt lower to accommodate their pregnant abdomens in over half of the responses to this question. This suggests that these subjects may have been particularly aware of the need to keep the lap belt low beneath the bulge of their pregnant abdomens, probably from their participation in this study. A few subjects reported that they felt the need to loosen their lap belts because of abdomen tenderness. A few reported curling or “roping” of the lap belt by the last test session, saying that the belt would no longer lie flat. About 30% of the time, subjects responded that the lap belt tended to ride up over the abdomen, and they needed to check and shift it lower frequently. A few subjects in the last test session reported that the lap belt stayed in place better now that their abdomen protruded more or that the baby had shifted position.

Subjects reported some effect on shoulder-belt position from their pregnant abdomen about 20% of the time. Several said that the shoulder belt rubbed against their neck or breasts. A few responded that they consciously tried to keep the shoulder belt routed between their breasts and alongside their pregnant abdomen. Others reported loosening the shoulder belt because of neck or breast discomfort.

On ten occasions, subjects reported that they had difficulties maintaining proper belt position when they wore winter coats. Since subjects were tested at different times throughout the year, this number of responses might be higher if all subjects were in their third trimester during the winter months.

3.12 Results for Subject-Selected Configurations

After measurements were completed for the fourth buck configuration in the fourth test session, the investigator adjusted the lap- and shoulder-belt anchorage locations and the pedal fore/aft position to determine if the subject could achieve a more comfortable configuration. The subject was also allowed to change the seatback angle, seat fore/aft position, and steering-wheel tilt angle as desired. The subject measurements from these subject-selected configurations were compared to the mean measurements for the two configurations with the same seat height in this test session. For example, if the subject's last standard test configuration was in the 270-mm seat height, the subject-selected measurements were compared to the mean measurements from the two fourth-session configurations with the 270-mm seat height. However, no statistically significant effects of subject stature or seat height were found for any of the measurements, so the data presented are means for all subjects for both seat heights and all statures.

In the final, subject-adjusted configuration, subjects moved their seat rearward an average of 36 mm ($p=0.001$). They also adjusted the pedals rearward (i.e., toward the steering wheel) by an average of 31 mm, so the mean H-point-to BOF distance is not significantly different from that of the fixed-buck configurations. Subjects also adjusted the steering-wheel angle to be more horizontal, from a mean angle relative to vertical of 26.6° in the standard test configuration to 28.1° in the subject-selected configuration ($p=0.024$). These adjustments resulted in a mean increase in abdomen-to-wheel clearance of 23.8 mm, from 79.5 to 103.3 ($p<0.0001$). However, steering wheel-to-uterus overlap did not change significantly.

Mean actual lap-belt angle increased from 48.6° to 52.6° ($p=0.009$) from a combination of moving the seat rearward and shifting the anchor point forward for most subjects. However, the steeper angles did not lead to a significant change in the location where the lap-belt centerline crossed the uterine midline, or to its height relative to the left and right ASIS landmarks.

Subjects usually shifted the shoulder-belt anchorage lower, leading to a change in mean actual shoulder-belt angle from 27.4° to 15.6° ($p=0.001$). This resulted in a slight shift inward of where the shoulder belt crossed the shoulder (from .331 to .322, $p=0.043$) and a marginal shift outward of where the shoulder belt crossed the clavicle (from .414 to .449, $p=0.054$). The location where the shoulder belt crossed the sternum did not change significantly.

Appendix I contains photos of subjects' selected seating configurations for the fourth visit for selected members of each stature group. As noted previously, most subjects chose one of the lower shoulder-belt anchorage points.

4.0 SUMMARY AND DISCUSSION

A comprehensive anthropometric study of twenty-two pregnant drivers over the course of their pregnancies was conducted using an adjustable and validated laboratory vehicle mockup. The test facility provided for testing with different vehicle package geometries and seat-belt anchor locations, and for three-dimensional measurement of body, belt, and steering-wheel landmarks and contours. The results provide for quantification and analysis of the spatial relationships between vehicle components, restraint systems, driver positioning and posture, and pregnant-abdomen anatomy and anthropometry in the automotive environment.

For the twenty-two subjects in this study, weight, abdomen depth, and fundal height were found to increase with gestational age, but these abdomen measurements were not correlated with subject stature – i.e., taller subjects did not have larger abdomens according to these measurements. Thus, the abdomen dimensions of short and tall women in this study were generally of similar size at a given gestational age. This finding conflicts with assumptions made by Culver and Viano (1990) who attempted to use scaling techniques to estimate pregnant abdomen size and shape for different sizes of women, as shown in Figure 1. Because of the lack of correlation between stature and abdomen size, data from all subjects were used without scaling to develop the abdomen profile for the second-generation pregnant abdomen.

Testing was conducted at two seat heights in the mid-to-high range of passenger vehicles, but the differences in results for these two conditions are generally small and statistically insignificant. For either seat height, subjects did not significantly change their preferred seat fore/aft position, seatback angle, or steering-wheel tilt angle to accommodate their growing abdomen over the course of pregnancy. As expected, shorter drivers sat further forward, and the abdomen-to-wheel-rim distance was therefore smaller for shorter subjects. The average abdomen-to-wheel-rim clearance of around 110 mm for the tallest (Group 5) subjects in their 9th month of pregnancy is, in fact, larger than the mean clearances of 90 to 100 mm for the shorter subjects (Group 1 and 2) in their 3rd month of pregnancy. Abdomen-to-wheel-rim clearance for all subjects decreases an average of 80 mm over the course of gestation. Clearance for the shortest subjects was 30 mm or less by the last test session, and the abdomens of some subjects contacted the steering-wheel rim.

The top of the uterus (fundus) lies below the steering-wheel rim until after the 6th month of pregnancy. By the 9th month, approximately one quarter of the uterus lies above the steering-wheel rim for all stature groups.

The results of the current study conducted in a laboratory seating buck are consistent with an earlier study conducted on pregnant subjects in their own vehicles. In both studies, pregnant drivers generally did not change their fore/aft seat position, seatback angle, or steering-wheel angles over the course of pregnancy. This led to decreasing distance between the abdomen and steering wheel as pregnancy progressed.

Many subjects commented that, although they positioned their lap belt low over the pelvis and underneath their pregnant abdomen in their own vehicles, the belt tended to ride up over the pregnant abdomen as they drove. In this regard, the lap-belt angle generally became more horizontal with increasing gestational age due to the increase in abdomen depth. Also, shorter women had shallower lap-belt angles because they position the seat closer to the pedals and further from the fixed lap-belt anchor points used in this study. Prior studies have shown that of women who choose not to wear seat belts while pregnant, nearly half state that poor belt fit is a contributor to that decision (Pearlman 1996).

The observed locations of the lap belt over the abdomen in this study during the later months of pregnancy are of particular interest. Even when the lap belt is properly placed directly over or below the ASIS landmarks, the pregnant abdomen can be loaded by the belt in a frontal crash, since between 50% and 80% of the uterus lies below the lap-belt centerline and protrudes significantly forward of the ASIS. Figure 73 shows the side view of data from one subject on her last session, including the abdomen profile, ASIS landmarks, and path of the lap-belt centerline. Neither of the nominal anchor-point locations used in the study, nor the subject-selected anchor points, improved on this situation.

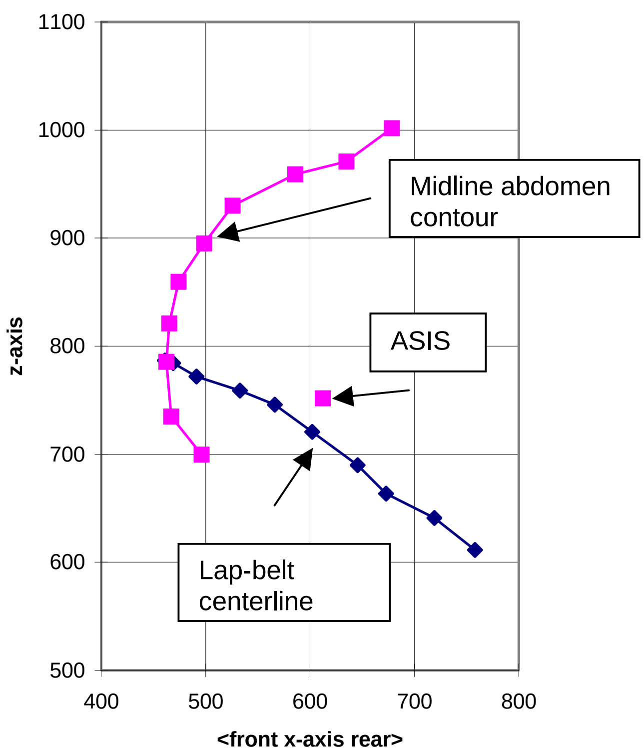


Figure 73. Relationship between lap-belt routing, ASIS, and abdomen contour in later months of pregnancy.

As might be expected, the shoulder-belt angle measured above the level of the shoulder in the side-view plane was unaffected by the pregnant abdomen. However, in the front view, the shoulder belt tended to cross the sternum higher and the clavicle closer to the center of the body in the later months of pregnancy. The nominal 20° shoulder-belt angle positioned the shoulder belt closer to the midpoints of the sternum and clavicle than the 60° nominal shoulder-belt angle, and therefore might tend to reduce belt loading of the neck. Interestingly, subject stature did not have a significant effect on these measures. A steeper angle might be expected with shorter subjects because of their lower shoulder, but their more forward seat position apparently compensates and results in the same shoulder-belt angles obtained with the taller subjects.

When subjects were allowed to adjust the pedal fore/aft location in the last test session, almost all subjects moved the pedals rearward, with a mean adjustment of 31 mm. This allowed the subjects to adjust the seat rearward and to tilt the steering wheel to be more horizontal. These adjustments resulted in an average increase in abdomen-to-wheel clearance of about 24 mm.

In the subject-selected configurations, most subjects adjusted the lap-belt anchorage forward to produce a steeper lap-belt angle, and commented that they felt this would help the belt stay in the proper location over time. However, these adjustments did not change where the lap-belt centerline crossed the pelvis relative to the ASIS landmarks or midline. Subjects generally moved the upper shoulder-belt anchorage lower, thereby decreasing the shoulder-belt angle. This helped to keep the belt away from the neck. The adjustment resulted in a change in the frontal-plane shoulder-belt angle that moved the belt inward relative to the shoulder and outward relative to the clavicle, routing the belt more vertically over the front of the shoulder.

5.0 CONCLUSIONS

This anthropometric study of pregnant motor-vehicle drivers has led to the following main observations and conclusions:

- Weight, abdomen depth, abdomen circumference, fundal height, hip breadth and ASIS breadth increase with gestational age. Maternal stature, BMI, buttock-knee length, and buttock-popliteal length do not.
- For this sample, pregnant abdomen size and shape, characterized by abdomen depth and circumference and fundal height, are not functions of maternal stature, but do depend on maternal weight. In this small sample, maternal pre-pregnancy weight and stature were relatively uncorrelated.
- With fixed pedals, pregnant drivers do not change their fore/aft seat position, steering-wheel angle, or seatback angle over the course of pregnancy to accommodate their increasing abdomen size. Their overall seated driving posture and position within the vehicle remains about the same throughout gestation.
- Abdomen-to-wheel clearance decreases with gestational age for all stature groups. Abdomen-to-wheel clearances are smaller for shorter subjects.
- The uterus remains below the lower rim of the steering wheel until about six months of pregnancy. After this time, the upper 20-35% of the uterus is higher than the lower steering-wheel rim, resulting in the potential for steering-wheel-rim loading of the uterus in the later months of pregnancy.
- Lap-belt angles become shallower with increasing gestational age because of the growing abdomen protrusion relative to a fixed anchorage location. Taller subjects have steeper lap-belt angles primarily because they position the seat more rearward. Lap-belt angles are also steeper with the 360-mm seat height during the early stages of pregnancy. Side-view shoulder-belt angles remain constant with gestational age and do not vary significantly with stature or seat height.
- When subjects were instructed to position the lap belt as low as possible beneath their pregnant abdomens, the lap-belt centerline was within +/- 20 mm of the ASIS on most subjects. However, even with the lap belt positioned over the bony pelvis, it crossed the pregnant uterus in the mid-sagittal plane at a level corresponding to 50-80% of the total uterus height. This potentially allows loading of the protruding soft tissues of the pregnant abdomen by the lap belt during a frontal impact.
- The shoulder-belt centerline crosses the sternum near its center until the last few weeks of pregnancy, when it crosses at a slightly higher level for both 20° and 60° nominal shoulder-belt angles. The shoulder-belt centerline crosses the shoulder at about one third the distance from the neck/shoulder junction to the greater tubercle of the humerus for all stature groups, shoulder-belt angles, and gestational ages. The shoulder-belt centerline crosses the clavicle at different points throughout gestation, moving closer to the sternoclavicular joint with increasing gestational age. The shallower shoulder-belt angle helped to maintain a shoulder-belt crossing closer to the clavicle centerline and sternum midpoint.
- The average abdomen size and shape from this study is significantly different from that of the first-generation pregnant abdomen. The results will be used to improve the abdomen anthropometry in the second-generation pregnant abdomen that is under development.

6.0 ACKNOWLEDGMENTS

This research was funded by General Motors (GM) pursuant to an agreement between GM and the U.S. Department of Transportation. The authors wish to thank members of UMTRI's Biosciences Division for their valuable input and technical support to the project. Brian Eby, Stewart Simonett, Jeff Lehman, and Jim Whitley contributed to the buck construction, instrumentation, and data acquisition efforts. Tracey Melville provided photographic support. Matt Reed and Miriam Manary helped with test design, statistical analysis, and data analysis. The authors also wish to recognize and thank the pregnant volunteers who participated in the study.

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Appendix A
Pilot Study of Pregnant Driver Anthropometry and Positioning in Production Vehicles

INTRODUCTION

A preliminary investigation of driver anthropometry during pregnancy was undertaken to determine how changes in body dimensions affect pregnant-driver positioning and relationships to vehicle components and restraint systems, and to determine if proper placement of lap and shoulder belt is maintained throughout pregnancy. Eleven women were recruited early in their pregnancy and periodically measured in their own vehicles over the course of gestation. Measurement sessions were conducted during the 3rd, 5th, 7th, and 9th months of pregnancy. Measurements taken manually at each session include abdomen-to-steering wheel rim distance, steering-wheel angle, selected fore/aft seat position, selected seatback angle, and the location of the lap and shoulder belts in relation to the pelvis and gravid uterus.

METHODS

The general nature and procedures of the study were described to subjects responding to local advertising during an initial phone interview. It was determined if the subject owned a vehicle that she drove regularly, and if she was planning to keep the vehicle for the duration of her pregnancy.

Upon arrival at UMTRI, the subjects were photographed to document their normal driving posture and belt-restraint positioning prior to exiting their vehicle. The subject then exited the vehicle and standard anthropometric measurements were taken to provide a general description of the subject's pre-pregnancy dimensions. Measurements taken are listed in Table A.1. These measurements were taken at every test session to determine how the body size and shape change during gestation. All measurements were collected without depressing the skin surface.

During the first test session it was determined if the subject's vehicle was equipped with a manual or six-way power seat, and if the steering wheel had tilt and/or vertical adjustment. Vehicle interior and component landmarks were established and/or targeted on rigid interior surfaces, so that the subject-selected seat, seatback, and steering-wheel positions and orientations could be easily verified at each session using a tape measure and an inclinometer. Inclinometer measures were adjusted for vehicle angle measured on the driver-side rocker panel.

Once the measurement landmarks were established, the subject was asked to return to her vehicle, position her seat belt as she normally would, and assume a posture for alert city driving. When the subject was seated comfortably, photographs were taken to document driving posture, belt-restraint positioning, and proximity of the body to the steering wheel. Measurements to define the subject's preferred seated position were taken and recorded. The measurements taken to document the positions of the lap and shoulder belts in relation to anatomical landmarks and the uterus are illustrated in Figures A.1 through A.3. In addition, the distance from the steering wheel to the gravid abdomen was documented, as shown in Figure A.4.

Table A.1
Anthropometric Measurements and Definitions

Measurement	Descriptions
	Standing Measurements
Stature without shoes	Subject stands erect and the vertical distance between the standing surface and the top of the subject's head is measured.
Shoe heel height	The subject's right shoe is removed and the thickness of the heel is measured using a special device. (Note: subjects were asked to wear the same shoes every test session).
Weight without shoes	The subject stands on a scale without wearing shoes.
Frontal arm reach	Subject stands with heels, buttock, and back against a flat vertical surface. The right arm is raised to a horizontal position with the elbow and fingers fully extended. The horizontal distance between the vertical surface and the tip of the middle finger is measured.
Shoulder-elbow length	Subject stands erect with upper arms hanging vertically at the sides and the elbows flexed 90 degrees so the forearms are horizontal. With the fingers extended and together, and the palms facing inward, the vertical distance between the acromion process and the bottom of the elbow (olecranon process) is measured.
Elbow-hand length	Subject stands erect with upper arms hanging vertically at the sides and the elbows flexed 90 degrees so the forearms are horizontal. With the fingers extended and together, and the palms facing inward, the horizontal distance between the back of the elbow to the tip of the middle finger is measured.
	Seated Measurements
Erect sitting height	Subject sits in an erect posture on a flat horizontal surface. The vertical distance between the sitting surface and the top of the head is measured.
PSIS height	Subject sits in an erect posture on a flat horizontal surface, with the feet on a flat horizontal surface such that the thighs are parallel and horizontal and the knees are flexed at 90 degrees. The right posterior superior iliac spine (PSIS) is located by palpating along the pelvic crests to locate the most posterior point of the crest. The vertical distance between the sitting surface and the top of the PSIS is measured.
Knee height	Subject sits in an erect posture on a flat horizontal surface, with the feet on a flat horizontal surface such that the thighs are parallel and horizontal and the knees are flexed at 90 degrees. The vertical distance between the footrest surface and the top of the knee is measured.
Popliteal height	Subject sits in an erect posture on a flat horizontal surface, with the feet on a flat horizontal surface such that the thighs are parallel and horizontal and the knees are flexed at 90 degrees. The vertical distance between the footrest surface and the inside junction of the thigh and the leg (i.e., the back of the knee) is measured.
Buttock-knee length	Subject sits in an erect posture on a flat horizontal surface, with the feet on a flat horizontal surface such that the thighs are parallel and horizontal and the knees are flexed at 90 degrees. The horizontal distance between the posterior aspect of the buttock to the front of the right knee is measured.

Table A.1 continued

Measurement	Descriptions
Buttock-popliteal length	Subject sits in an erect posture on a flat horizontal surface, with the feet on a flat horizontal surface such that the thighs are parallel and horizontal and the knees are flexed at 90 degrees. The horizontal distance between the posterior aspect of the buttock to the inside junction of the leg and the thigh at the back of the knee is measured.
Hip breadth	Subject sits in an erect posture on a flat horizontal surface, with the feet on a flat horizontal surface such that the thighs are parallel and horizontal and the knees are flexed at 90 degrees. The maximum breadth of the hip/thigh is measured.
Abdomen breadth	Subject sits in an erect posture on a flat horizontal surface, with the feet on a flat horizontal surface such that the thighs are parallel and horizontal and the knees are flexed at 90 degrees. The breadth of the abdomen is measured at the level of the umbilicus.
ASIS breadth	Subject sits in an erect posture on a flat horizontal surface, with the feet on a flat horizontal surface such that the thighs are parallel and horizontal and the knees are flexed at 90 degrees. The right and left anterior superior iliac spines (ASIS) are located by palpating along the pelvic crests to locate the most anterior point of each crest. The subject is asked to hold a fingertip on each ASIS for reference, and the distance between the two landmarks is measured.
PSIS-abdomen breadth	Subject sits in an erect posture on a flat horizontal surface, with the feet on a flat horizontal surface such that the thighs are parallel and horizontal and the knees are flexed at 90 degrees. The distance from the PSIS to most prominent point on the abdomen is measured.
Seated fundal height	Subject sits in an erect posture on a flat horizontal surface, with the feet on a flat horizontal surface such that the thighs are parallel and horizontal and the knees are flexed at 90 degrees. The distance along the surface of the abdomen from the superior margin of the pubic symphysis to the uterine fundus (top of uterus) is measured.
Abdomen circumference	Subject sits in an erect posture on a flat horizontal surface, with the feet on a flat horizontal surface such that the thighs are parallel and horizontal and the knees are flexed at 90 degrees. The maximum circumference of the abdomen is measured at the level of the umbilicus.

Horizontal Distances to Shoulder-Belt Centerline:

1. Sternoclavicular Junction
2. Acromion Process
3. Medial Aspect of Breast
4. Xiphoid Process
5. Uterine Fundus
6. Umbilicus
7. Right Lateral Uterine Aspect

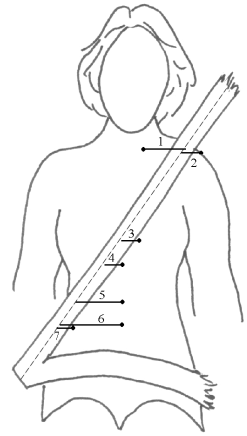


Figure A.1. Horizontal shoulder-belt measurements.

Vertical Distances to Shoulder-Belt Centerline:

8. Sternoclavicular Junction
9. Acromion Process
10. Medial Aspect of Breast
11. Xiphoid Process
12. Uterine Fundus
13. Umbilicus
14. Right Lateral Uterine Aspect

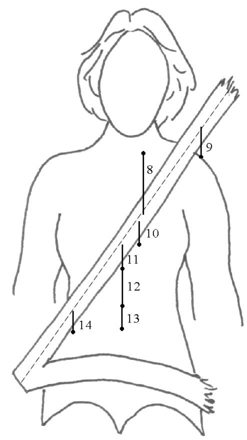


Figure A.2. Vertical shoulder-belt measurements.

Distances to Lap-Belt Centerline:

15. Right Lateral Uterine Aspect
16. Right ASIS
17. Umbilicus
18. Superior margin of the Pubic Symphysis
19. Left ASIS
20. Left Lateral Uterine Aspect

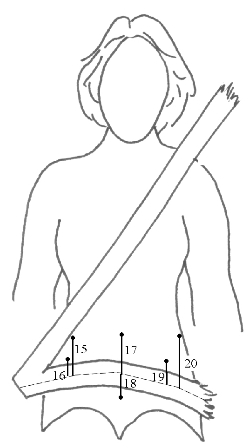


Figure A.3. Vertical lap-belt measurements.

Bottom of Steering Wheel to:

9. Closest Point on the Abdomen
10. Closest Point on the Abdomen to the Umbilicus
11. Uterine Fundus
12. Pubic Symphysis

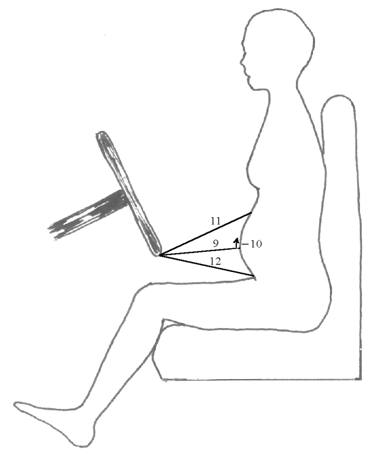


Figure A.4. Measurements from bottom of steering-wheel rim to abdomen.

RESULTS

Anthropometry

Although subjects were not recruited to fill specific height categories, good ranges of stature and weight are represented by subjects in this study, as shown in Figure A.5. Subject anthropometry measured at all sessions is listed in Table A.2. Several anthropometric variables measured at each test session, including weight, abdomen depth, abdomen circumference, and fundal height, increased with gestational age, as shown in Figures A.6 through A.9. Scatter plots of abdomen depth, abdomen circumference, and fundal height versus stature are presented in Figures A.10 through A.12. No correlation between subject stature and size of the pregnant abdomen is seen.

Figures A.13, A.14, and A.15 show scatter plots of abdomen depth, abdomen circumference and fundal height versus weight for the four measurement sessions. All three measurements show a positive correlation between uterine size and subject weight.

Table A.2
Subject Anthropometry Measured at All Test Sessions

Subject	Session	Gestational Age (weeks)	Weight (lb)	Stature (mm)	Heel Height (mm)	Buttock-Knee Length (mm)	Buttock-Popliteal Length (mm)	Hip Breadth (mm)	Uterine Breadth (mm)	ASIS Breadth (mm)	PSIS-Abdomen Depth (mm)	Fundal Height (mm)	Abdomen Circumference (mm)
1	1	9.3	169	1608	24	567	469	426	--	250	272	--	1040
1	2	21.6	168	1608	23	569	467	442	262	255	294	230	1098
1	3	29.3	175	1598	14	574	480	448	320	252	329	335	1159
1	4	36.5	181	1601	16	569	481	455	317	254	361	390	1205
2	1	9.3	123	1630	25	551	156	371	--	265	210	--	890
2	2	20.5	135	1631	17	550	152	402	284	266	247	235	1005
2	3	29.5	145	1624	25	570	475	412	295	265	295	290	1062
2	4	37	152	1624	25	563	468	416	294	262	321	315	1120
3	1	8.2	118	1633	25	535	457	348	--	227	166	--	760
3	2	21.2	135	1635	14	548	449	377	260	232	232	205	920
3	3	28.3	141	1631	26	52	472	370	275	220	270	270	970
3	4	36.5	149	1632	25	558	474	364	275	246	296	330	1060
4	1	11	131	1702	19	577	485	386	--	249	188	--	752
4	2	22	142	1713	8	581	485	409	285	254	228	180	940
4	3	29.1	149	1700	14	582	487	387	304	259	264	290	962
4	4	37.6	163	1712	10	587	494	416	299	243	303	350	1045
5	1	10.4	134	1570	25	581	480	387	--	208	199	--	875
5	2	20.4	140	1566	26	575	474	384	232	207	236	185	920
5	3	31.5	145	1570	15	581	476	388	275	223	288	285	1002
5	4	37.3	148	1574	25	575	486	380	275	232	322	330	1069
6	1	10.3	131	1595	26	572	476	392	--	224	198	--	870
6	2	21.1	143	1595	25	575	471	382	236	230	222	115	900
6	3	31.2	153	1595	25	575	470	411	249	230	282	280	1018
6	4	37.3	160	1591	25	580	503	410	268	233	313	320	1047
7	1	8.4	156	1580	18	577	492	443	--	201	243	--	925
7	2	23.4	174	1585	22	590	487	437	316	216	332	325	1117
7	3	31	179	1572	14	584	475	458	303	210	348	360	1133
7	4	37	187	1575	14	590	480	458	324	215	348	375	1220
8	1	13.2	161	1636	12	593	497	414	--	211	264	--	950
8	2	23.4	167	1639	7	580	494	411	283	213	308	280	990
8	3	30.5	169	1646	8	586	480	434	305	223	315	345	1115
8	4	36.5	178	1630	7	587	481	412	300	220	368	370	1177
9	1	12.2	120	1577	31	566	466	368	--	237	210	--	835

Table A.2
Subject Anthropometry Measured at All Test Sessions

Subject	Session	Gestational Age (weeks)	Weight (lb)	Stature (mm)	Heel Height (mm)	Buttock-Knee Length (mm)	Buttock-Popliteal Length (mm)	Hip Breadth (mm)	Uterine Breadth (mm)	ASIS Breadth (mm)	PSIS-Abdomen Depth (mm)	Fundal Height (mm)	Abdomen Circumference (mm)
9	2	21	128	1567	12	577	469	367	237	243	265	202	915
9	3	28.5	133	1566	12	580	502	389	273	254	284	285	951
9	4	37.2	143	1557	20	588	460	396	283	240	325	335	1056
11	1	8.5	157	1591	15	576	490	404	--	230	275	--	1065
11	2	20.6	175	1603	18	578	497	410	30 4	244	314	210	1200
11	3	29	189	1615	27	578	483	429	332	256	352	305	1244
11	4	36.5	200	1612	26	582	508	439	339	256	370	370	1254
12	1	13.4	154	1693	24	582	482	440	--	265	237	--	904
12	2	20.3	165	1700	23	591	499	455	279	265	267	210	990
12	3	31.1	174	1690	24	590	478	453	274	260	300	300	1044
12	4	36.5	178	1692	25	588	480	463	285	260	325	335	1088

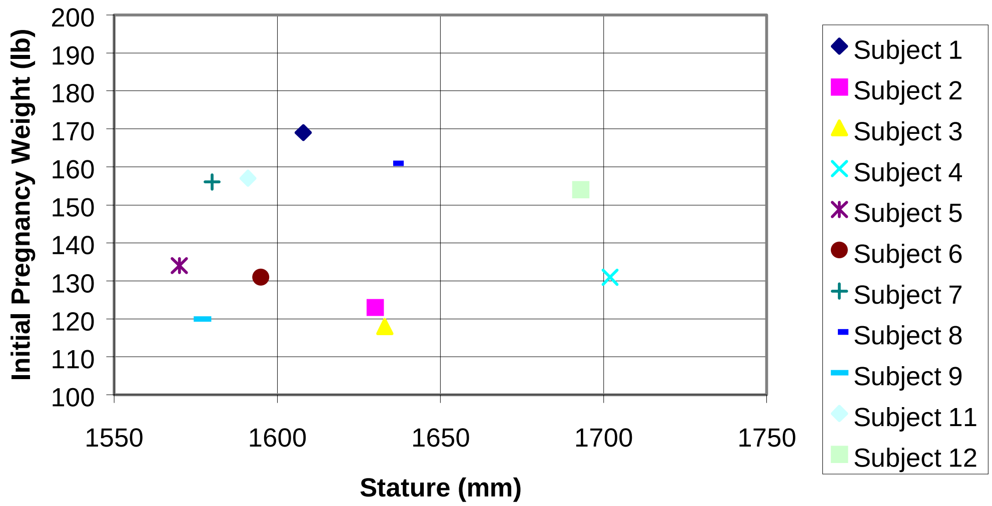


Figure A.5. Subject initial-session weight vs. stature.

Figure A.6. Change in weight relative to first session,
as a function of gestational age.

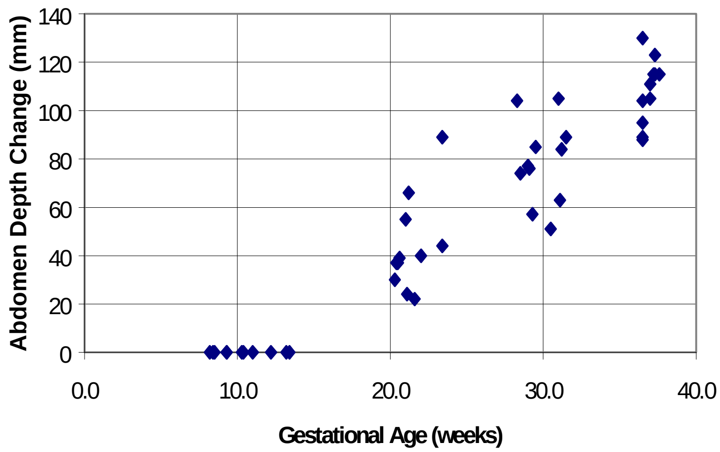


Figure A.7. Change in abdomen depth relative to first session, as a function of gestational age.

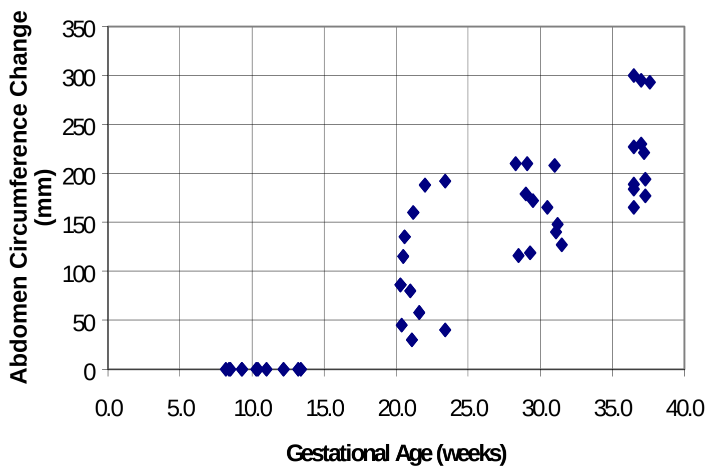


Figure A.8. Change in abdomen circumference relative to first session, as a function of gestational age.

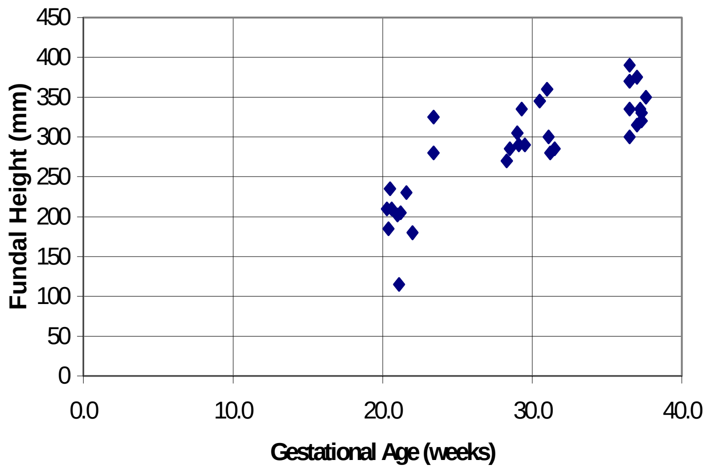


Figure A.9. Fundal height as a function of gestational age.

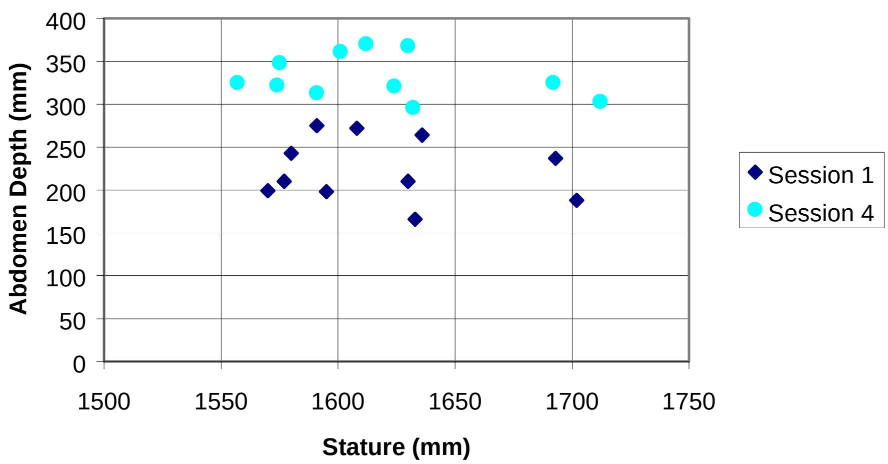


Figure A.10. Abdomen depth vs. stature (R=-0.153).

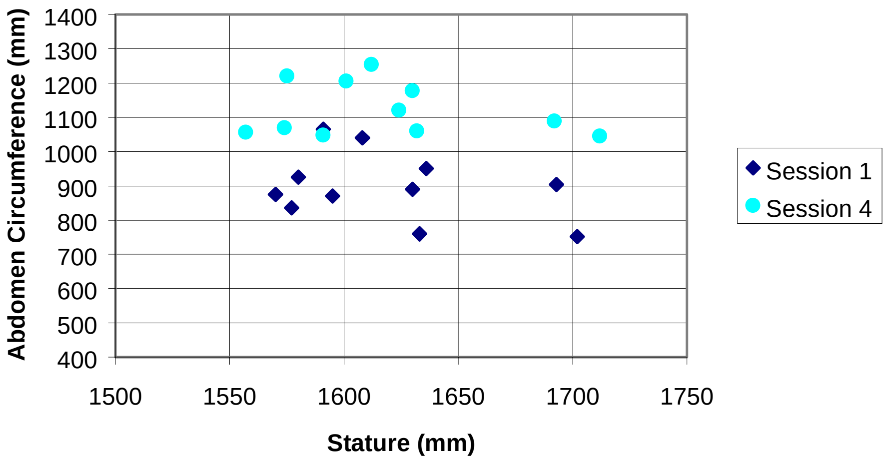


Figure A.11. Abdomen circumference vs. stature (R=-0.153).

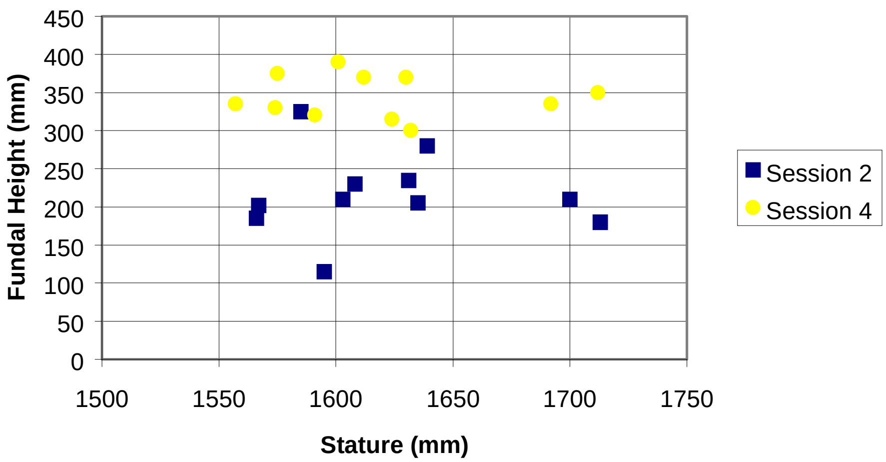


Figure A.12. Fundal height vs. stature (R=-0.072).

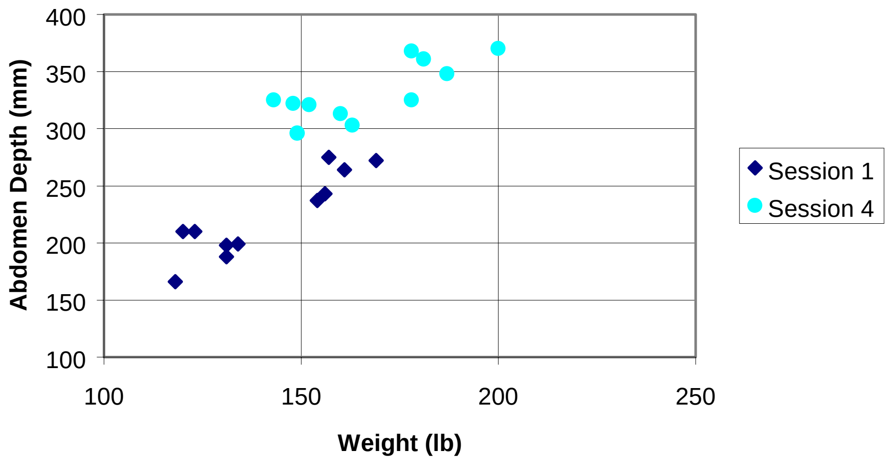


Figure A.13. Abdomen depth vs. weight (R=0.830).

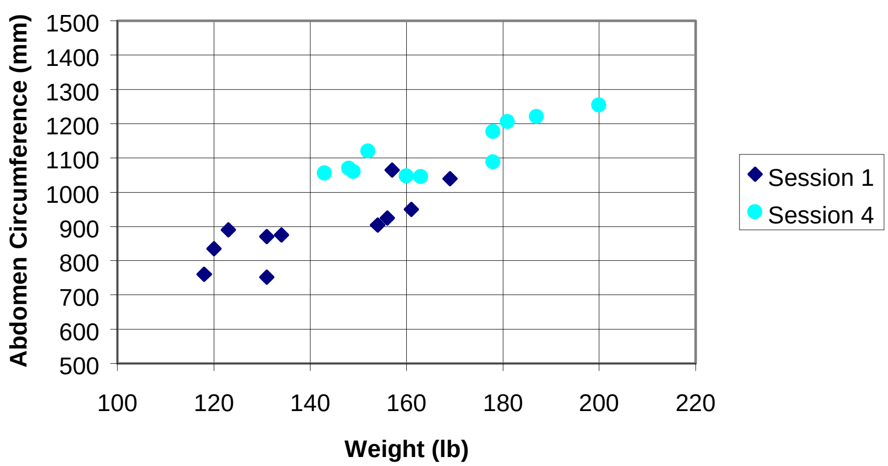


Figure A.14. Abdomen circumference vs. weight (R=0.862).

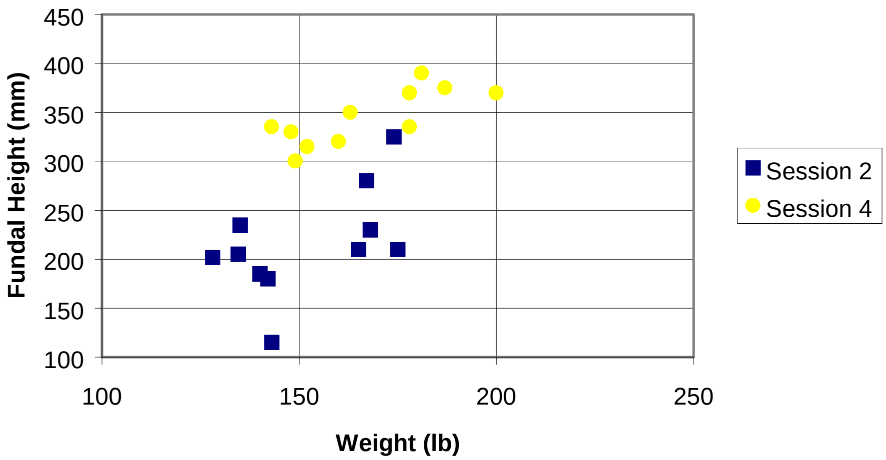


Figure A.15. Fundal height vs. weight (R=0.599).

Subject Vehicle Information

Table A.3 lists the make and model of the vehicles driven by each subject, as well as transmission type, type of seat-track, steering-wheel adjustments, and the type of belt restraint. Differences in vehicle factors, such as seat height, transmission type, and steering-wheel-to-ball-of-foot distance that may influence the driver's preferred seated position are variables that were not controlled in this study.

Table A.3
Vehicle Make and Model Information

Subject #	Year	Make	Model	Transmission Type	Seat Track Type	Steering Wheel Adjustment	Restraint Type
1	1993	Dodge	Shadow	Automatic	Manual	Fixed	3-point
2	1995	Toyota	Corolla	Automatic	Manual	Fixed	3-point
3	1995	Toyota	Corolla	Manual	Manual	Vertical	3-point
4	1994	Ford	Escort	Manual	Manual	Tilt	2-pt/2-pt
5	1993	Jeep	Grand Cherokee	Automatic	Power	Tilt	3-point
6	1989	Toyota	Tercel	Manual	Manual	Vertical	3-point
7	1995	Jeep	Cherokee	Automatic	Manual	Fixed	3-point
8	1992	Mercury	Topaz	Manual	Manual	Tilt	2-pt/2-pt
9	1990	Honda	Civic	Manual	Manual	Vertical	2-pt/2-pt
11	1992	Nissan	Stanza	Automatic	Manual	Vertical	2-pt/2-pt
12	1993	GMC	Safari	Automatic	Manual	Tilt	3-point

Selected Seat Positions and Seatback Angles

Seven of the eleven subjects indicated that they shared their vehicle with a spouse, and occasionally were required to readjust the seat prior to driving. Figures A.16 and A.17 show the changes in fore/aft seat position and seatback angle from the positions measured in the first test session, for all subjects. As indicated, there is no consistent pattern to changes in either variable and, with three exceptions, subjects generally maintained their original seat position and seatback angle throughout pregnancy. The exceptions are subjects 2, 4, and 11. Subject 2 adjusted the seat more rearward and her seatback angle more upright as her pregnancy progressed. For the third test session, Subject 4 moved the seat 80 mm forward of the position she selected in the second session, and she increased the seatback angle by 10° respectively to relieve lower-back pain. Subject 11 moved the seat more rearward in the third and fourth test sessions, but did not change the seatback angle significantly.

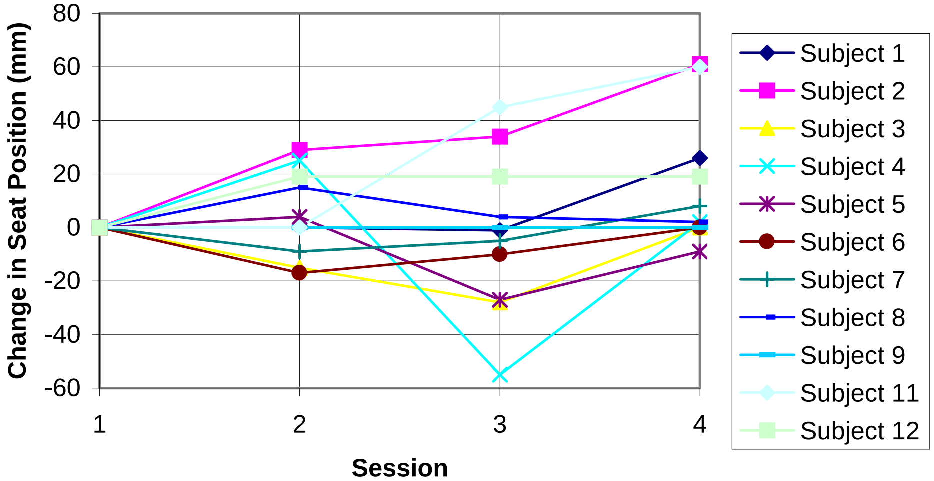


Figure A.16. Subject-selected seat position relative to the seat position selected during first test session.

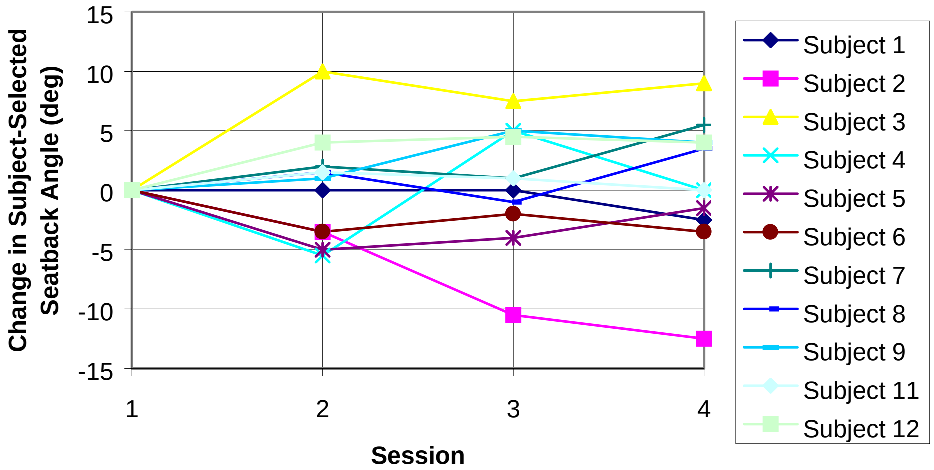


Figure A.17. Subject-selected seatback angle relative to the angle selected in the first test session.

Abdomen-to-Steering-Wheel Rim Distance

As shown in Figure A.18, the distance from the abdomen to the steering-wheel rim decreased for every subject as their pregnancy progressed. In the fourth session, there was less than 50 mm clearance between the lower steering-wheel rim and the abdomen for many subjects, and one subject's abdomen was in contact with the lower rim, as shown by the photos of Figure A.19. In contrast, the abdomens of three of the taller women were 100 mm or more from the lower steering-wheel rim at the fourth measurement session.

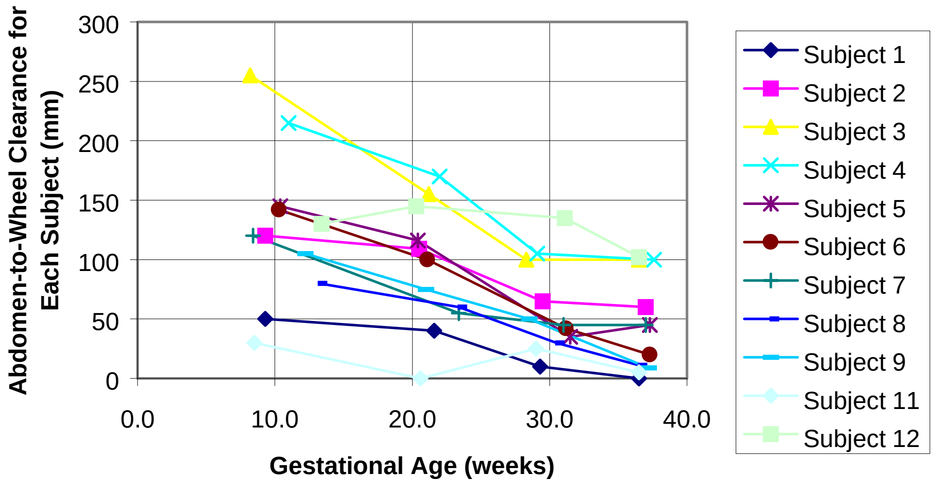


Figure A.18. Abdomen-to-steering-wheel-rim distance as a function of gestational age.

Session 1

Session 2

Session 3

Session 4

Figure A.19. Side view of Subject 1 (1608-mm stature) seated in 1993 Dodge Shadow showing decrease in abdomen-to-steering- wheel-rim distance with increasing gestational age.

Lap- and Shoulder-Belt Positioning

Subjects were not instructed on proper seatbelt usage during pregnancy in this study, but were asked to position their lap and shoulder belt the way they normally do. Of the eleven subjects, ten properly wore their lap and shoulder belt. Subject 8 consistently wore her shoulder belt out of position, either off of the shoulder or routed across the top of the pregnant abdomen and under the arm. The shoulder belt data for this subject were considered to be outliers and were removed from the data set.

As shown in Figures A.20 and A.21, the lap-belt centerline showed a slight tendency to shift down relative to the anterior superior iliac spines (ASIS) of the pelvis over the course of these pregnancies, indicating proper positioning for loading of the bony pelvis. However, even with the lap belt remaining below the ASIS during the four measurement sessions, the distance from the pubic symphysis to the lap-belt centerline tended to increase with gestational age for over half of the subjects, as shown in Figure A.22.

The location of the shoulder belt was documented by two measurements: the vertical distance of the shoulder-belt centerline above the bottom of the sternum or xiphoid process, and the horizontal distance of the shoulder-belt centerline to the left or right of the xiphoid process. These distances are illustrated in Figure A.23. Figures A.24 and A.25 show changes in these measurements over the course of pregnancy for all subjects. There are no clear or consistent trends for either measure, but several subjects did show a significant change in either the horizontal location or vertical location of the shoulder belt between the third and fourth sessions.

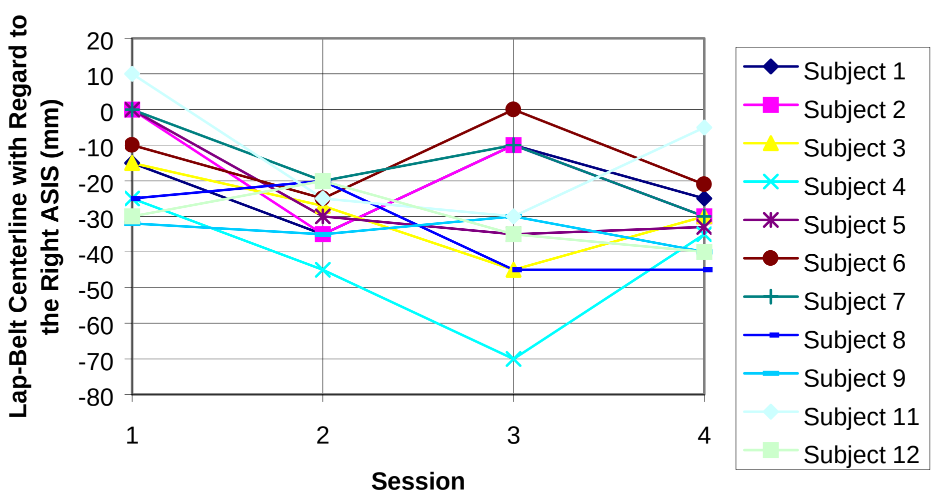


Figure A.20. Vertical location of the lap-belt centerline relative to the right ASIS.

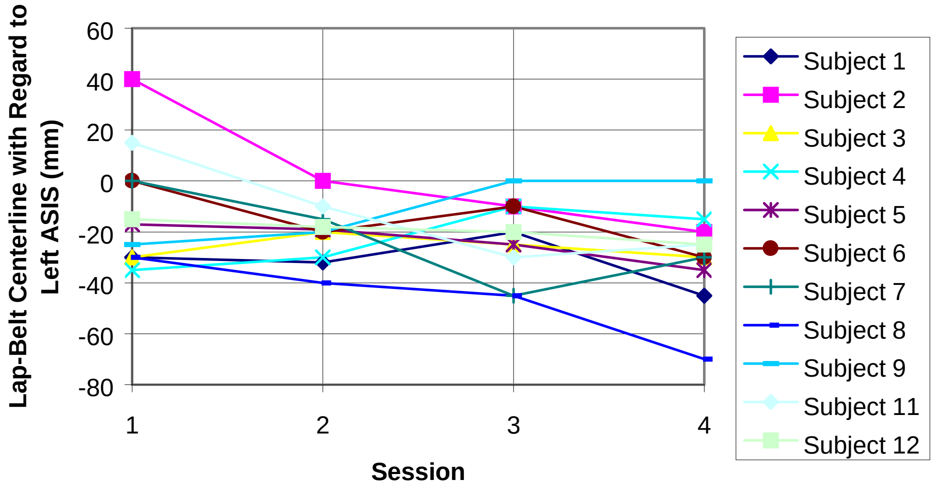


Figure A.21. Vertical location of the lap-belt centerline relative to the left ASIS.

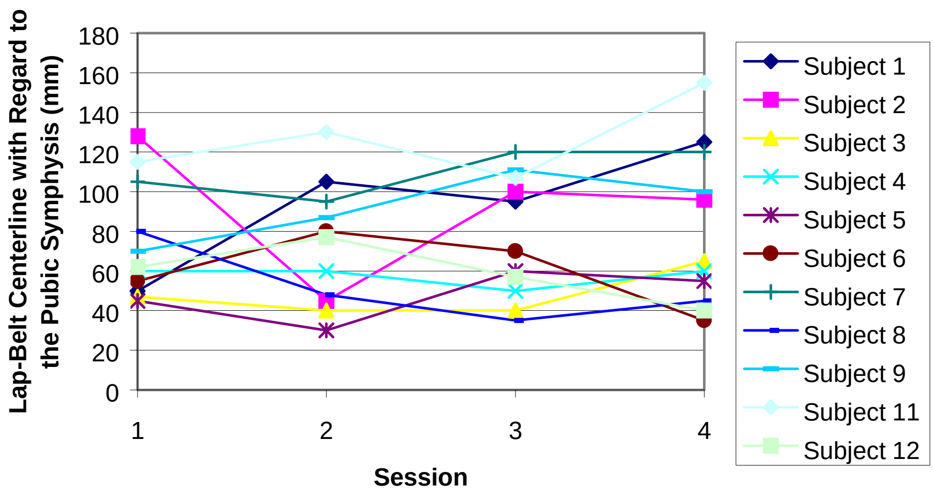


Figure A.22. Vertical location of the lap-belt centerline relative to the pubic symphysis.

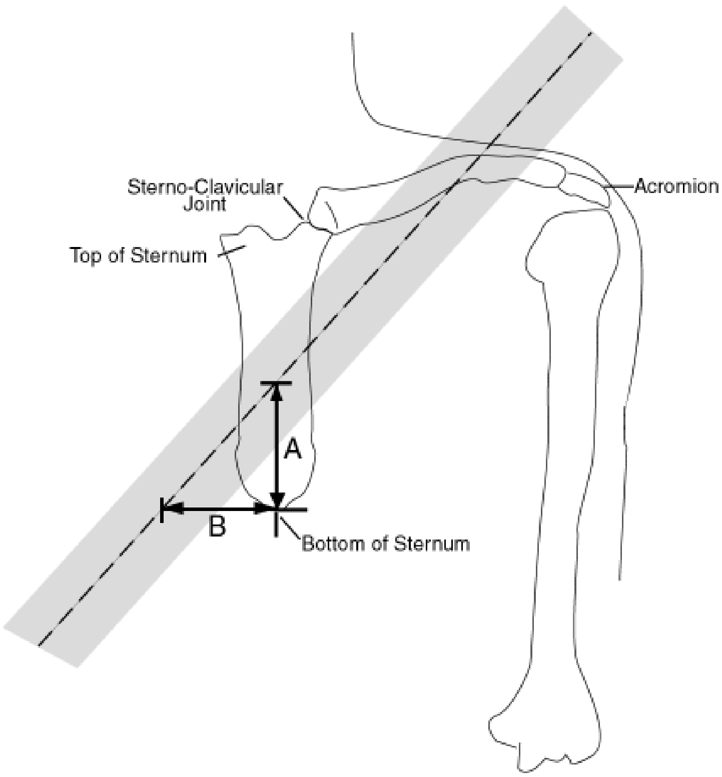


Figure A.23. Measurements for locating the shoulder belt centerline relative to the xiphoid process.

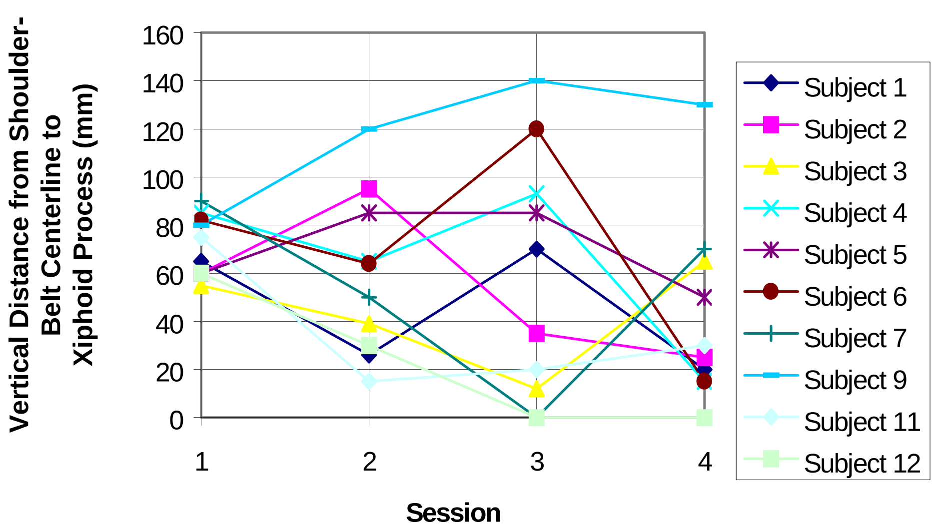


Figure A.24. Vertical distance from the shoulder-belt centerline to the xiphoid process (measurement A in Figure A.23).

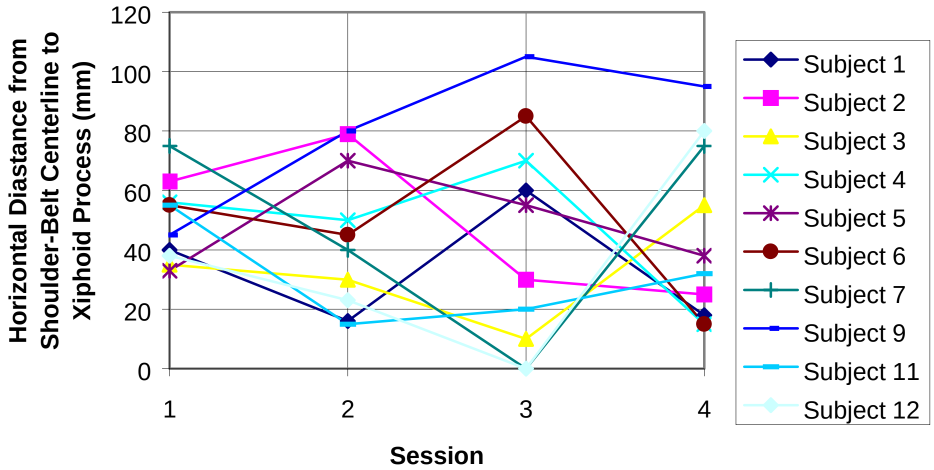


Figure A.25. Horizontal distance from the shoulder-belt centerline to the xiphoid process (measurement B in Figure A.23).

SUMMARY AND DISCUSSION

This pilot study was undertaken prior to the full-scale study of this report to obtain some preliminary information on how changes in body dimensions during pregnancy affect driver positioning inside the vehicle, and the positioning of the belt and steering wheel relative to the pregnant abdomen and uterus. The results provide anthropometric and positioning information of subjects in production vehicles normally driven by the subjects, and thereby provide real-world data.

Of the eleven subjects that participated in this study, ten wore their lap and shoulder belts properly without instruction. A majority of the subjects lowered the lap belt in relation to the ASIS as their pregnancy progressed. Shoulder-belt placement tended to be less consistent, and subjects tended to slacken the belt slightly as their pregnancies progressed to reduce pressure on the breasts and abdomen.

Subjects did not make any significant or consistent adjustments in their selected fore/aft seat position, seatback angle, or steering-wheel angle to accommodate their growing abdomen over the course of gestation. As the pregnancies progressed, abdomen-to-steering-wheel distances decreased and the abdomens of many subjects were less than 50 mm from the steering wheel in the fourth measurement session. One subject's abdomen was in contact with the steering wheel during the fourth test session.

Appendix B
Subject Recruitment Forms:
Health Screening and Consent Forms

SUBJECT #: ____________

HEALTH QUESTIONNAIRE
(please print)

DATE: ________________

NAME:____ PHONE (S): ______________________
Last First Middle

____

ADDRESS: ____
Street City State Zip

SOC. SEC. NO.: ____________________________ BIRTHDATE: ____________________ AGE: ______________

FIRST DAY OF LAST MENSTRUAL PERIOD: _____________ PREGNANCY DUE DATE: _____________

NUMBER OF PREGNANCIES: ______________ NUMBER OF BIRTHS: ______________

If you miscarried during a pregnancy, how many weeks were you pregnant? __________________________

DIRECTIONS: Answer all questions. If you are uncertain as to how to best answer a question please circle *Yes* or *No* and explain further either at space provided after question or at the end of the questionnaire with the letter and # marked.

1. Do you have a valid and current driver's license? *Yes* *No*
   a. Approximately how many miles do you drive a year?____
2. Does severe rheumatism (or arthritis) interfere with your work? *Yes* *No*
3. Are you under a doctor or midwife's care? *Yes* *No*
   a. If yes, give name of doctor or midwife: ____
4. Are you currently taking any medications? *Yes* *No*
   a. If yes, give name of medication: ____
5. Do you need glasses for reading or other close work? *Yes* *No*
6. Do you need glasses for seeing things at a distance? *Yes* *No*
7. Were you ever in an automobile accident where you might have suffered "whiplash" or neck injury? *Yes* *No*
8. Has a doctor ever said your blood pressure was too high or too low? *Yes* *No*
9. Do you have pains in the back or neck that make it hard for you to keep up with your daily activities? *Yes* *No*
10. Are you troubled by a serious bodily disability or deformity? *Yes* *No*
    a. If yes, please explain: ____
11. Were you ever knocked unconscious? *Yes* *No*
    a. If yes, please explain: ____
12. Have you ever had a serious injury? *Yes* *No*
    a. If yes, please explain: ____
13. Do you have any pregnancy complications? *Yes* *No*
    a. If yes, please explain: ____

Additional comments: (Please include date, symptoms, frequency of occurrence, and any other relevant data)

* NOTE: This questionnaire modified from the Cornell Medical Index for the R.I.W.U. multiphase testing, June 1951.

The University of Michigan Transportation Research Institute
Research Involving Human Subjects

INFORMED CONSENT FOR EXPERIMENTAL PROCEDURE

Crash Protection and ATD Abdomen Development for Pregnant Women and the Unborn Fetus: Seated Anthropometry During Pregnancy

Lawrence W. Schneider, Ph.D., Project Director
Research Scientist and Head, Biosciences Division, UMTRI

Mark D. Pearlman, M.D., Principal Investigator
Department of Obstetrics and Gynecology, University of Michigan Medical Center

Co-Investigators: Bethany Eby & Kathleen D. Klinich, UMTRI Biosciences

The purpose of this study is to investigate the changes in body dimensions of pregnant women over the period of gestation, and to determine the effects of these changes on restraint system fit and seat and body positioning in vehicles. The results of this study will be used to aid in the design of an improved abdomen for the pregnant test dummy.

I agree to allow several standard measurements to be taken that will describe my general body proportion and size. If I qualify for one of the height categories in the study, I will be asked to adjust the seat front-to-back position, seatback recliner angle, steering wheel angle and seat belt to my preferred positions in an adjustable laboratory seating buck that simulates the interior of a vehicle. I will be asked to repeat this procedure for several different test conditions in a test session lasting approximately 2 hours. I will be asked to return to UMTRI to repeat the test session three additional times during my pregnancy.

I understand that my participation in this study is voluntary and is conditional upon review of my responses to a health questionnaire and my physical qualifications with regard to experimental design criteria. I understand that I will be paid for my participation at a rate of $10/hr. I may refuse to participate in or withdraw from the study at any time without penalty or loss of benefits to which I may be otherwise entitled.

The University of Michigan Transportation Research Institute is a research organization and, as such, my records and personal information may be reviewed by research staff. My records will be kept confidential to the extent provided by federal, state and local law. I understand that data used in scientific publications and presentations will be provided only in coded form that will not identify me.

In the unlikely event of physical injury resulting from research procedures, the University will provide first-aid medical treatment. Additional medical treatment will be provided in accordance with the determination by the University of its responsibility to provide such treatment. However, the University does not provide compensation to a person who is injured while participating as a subject in research.

If significant new knowledge is obtained during the course of this research which may relate to my willingness to continue participation, I will be informed of this knowledge. The person(s) below listed may be contacted for more information about any aspect of this study. Any questions or concerns about my rights as a research subject, may be directed to the Office of Patient-Staff Relations, L5003 Women's Hospital, Box 0275, Telephone 763-5456.

One copy of this document will be kept together with research records on this study. A second copy has been given to me.

I have read the information given above. I understand the meaning of this information. I agree to the conditions set forth above and have had an opportunity to discuss my concerns regarding my participation in the proposed study. I hereby consent to participate in the study.

Mother's name (please print) ____________________ Father's name (please print) ____________________

Mother's signature: ____________________________ Father's signature: ____________________________

Date: ____ Date: ____

Investigator(s): Lawrence W. Schneider, Ph.D. 936-1103 (work), 996-3861 (home)

Date of IRBMED Initial Approval: 12/5/96 Date of IRBMED Expiration: 12/5/97
IRBMED Archive # 1996-516 Date of Most Recent Version of Consent Form Approval: 4-10-97

Appendix C
Definitions of Anthropometric Landmarks

Table C1: Definitions of Anthropometric Landmarks

Landmark	Description
Abdomen surface	Up to 60 points on undepressed abdomen surface collected in an estimated grid pattern.
Acromion, left and right	Undepressed skin surface point of the most anterior acromial process.
ASIS (L), ASIS(R)	Depressed skin surface point over anterior superior iliac spine. Located by palpating along the iliac crest to locate the most anterior point on the ilium.
C7	Depressed skin surface point over most posterior point on the C7 spinous process.
Corner of eye	Undepressed skin surface point at the most lateral point of the right eye.
Fundus	Skin surface measurement of the palpated superior margin of the uterus.
Glabella	Undepressed skin surface point at the most anterior prominence on the brow on the midsagittal plane.
Greater tubercle of humerus	Undepressed skin surface point of the most lateral point on the right greater tubercle of the humerous.
Heel contact	Point where most posterior point on subject's heel contacts floor.
Infraorbitale	Undepressed skin surface point at the lowest point on the anterior border of the bony eye socket.
Lateral aspect of uterus, L & R	Skin surface point of left and right sides of the uterus at the level of the umbilicus.
Lateral Femoral Condyle	Undepressed skin surface point at the most lateral prominence of the right femoral condyle.
Lateral humeral epicondyle	Undepressed skin surface point of the most lateral point on the humeral epicondyle.
Lateral maleolus	Undepressed skin surface point at the most lateral prominence of the right lateral malleolus.
Lateral neck	Undepressed skin surface point on left side of neck midway between ear and shoulder.
Manubrium	Undepressed skin surface point at the most superior margin of the jugular notch of the manubrium in the midline of the sternum.
Menton	Undepressed skin surface point of the tip of the chin in the midsagittal plane.
Midline1-8	Eight points approximately evenly spaced on undepressed skin surface points between fundus and pubic symphysis.
Midshoulder	Undepressed skin surface point on top of the left shoulder midway between the neck and the tip of the shoulder.
Neck/shoulder junction	Undepressed skin surface point at which the neck meets the left shoulder.
Occipital Protuberance	Undepressed skin surface point at the most posterior point on the occipital prominence.
Pelvic thigh junction (actual)	Depressed skin surface point of pelvis and thigh junction.
Pelvic thigh junction (surface)	Point where abdomen/pelvis and thigh visibly meet.
PSIS(L), PSIS(R)	Depressed skin surface point over posterior superior iliac spine. Located by palpating at the posterior margin of the iliac crest adjacent to the sacrum.
Pubic symphysis (PS)	Anterior-superior margin of the pubic symphysis. Subject is trained, using a model skeleton, to locate point with probe. Subject is instructed to compress the tissue toward the bone to the extent comfortable.
Sterno-clavicular junction	Undepressed skin surface point at the most anterior point of the junction between the sternum and clavicle.
Styloid process	Undepressed skin surface point at the most lateral point of the ulnar styloid process.
Supra patella	Undepressed skin surface point at the most superior point of the patella.
T4,T8,T12,L3,L5	Depressed skin surface point over most posterior point on corresponding spinous process.
Top head	Undepressed skin surface point at the most superior point on the head.

Landmark	Description
Tragion	Undepressed skin surface point of right ear where most anterior superior point meets the head.
Transverse abdomen 1-8	Undepressed skin surface point of eight estimated evenly spaced points at umbilicus level from left to right side of subject.
Umbilicus	Undepressed skin surface point at the umbilicus.
Xiphoid	Undepressed skin surface point marking the inferior margin of the sternum along the sternal midline.

Appendix D
Test Questionnaires

Subject Comments

Time _______ Date ________ Condition ____________ Subject No. ________

1. Now that you have selected your preferred seat position, seatback angle, and steering wheel angle, please place a check mark in the box that best describes the position of your body, torso, legs, etc. with regard to the following questions. If your response is anything other than "just right" please explain why you are not comfortable with regard to positioning.

a. Steering wheel fore/aft position

too close			just right			too far

comments: ____

b. Steering wheel tile angle

too angled			just right			too vertical

comments: ____

c. Gas pedal fore/aft

too close			just right			too far

comments: ____

d. Seatback angle

too upright			just right			too reclined

comments: ____

e. Seat cushion tilt angle

too low in front			just right			too high in front

comments: ____

f. Seat cushion length

too short			just right			too long

comments: ____

g. Steering wheel-to-leg clearance

too small			just right			too large

comments: ____

	too small			just right			too large
h. Wheel-to-abdomen clearance							

comments: ____

	too far from neck			just right			too close too neck
i. Shoulder belt fit							

comments: ____

2. Do you feel that you have compromised your preferred seated position to accommodate your growing abdomen? If so please explain. ____

____

____

3. Have you adjusted the lap belt differently to accommodate your growing abdomen? If so please explain.

____

____

____

4. Have you adjusted the shoulder belt differently to accommodate your growing abdomen? If so please explain. ____

____

____

Automobile Safety Restraints In Pregnant Women

Subjective Questionnaire

Subject # ____________ Date ________________

Visit # ____________ Time ________________

With regard to driving your own vehicle, please answer the following questions:

1. What vehicle do you primarily drive? ____________________________________

2. Do you feel that you have readjusted your seat fore/aft position in the past two months to accommodate for driving during your pregnancy? If so please explain. __________

____

____

3. Do you feel that you have readjusted your seatback angle in the past two months to accommodate for driving during your pregnancy? If so please explain. ___________

____

____

4. Do you feel that you have readjusted your steering wheel angle in the past two months to accommodate for driving during your pregnancy? If so please explain. __________

____

____

5. Have you adjusted the way you wear your lap belt in the past two months to accommodate pregnancy? If so please explain. ______________________________

____

____

6. Have you had difficulty maintaining the lap belt in the optimal position, low on the pelvis and below your protruding abdomen? If so please explain. _________________

____

____

7. Have you adjusted the way you wear your shoulder belt in the past two months to accommodate pregnancy? If so please explain. _________________________________

____

____

8. Have you modified your vehicle or apparel (not including maternity clothing) to accommodate for driving during your pregnancy? If so please explain. ____________

____

____

Appendix E

Anthropometry Data

Table E1
Subject Anthropometry at First Test Session

Subject	Age (years)	Gestational Age (weeks)	Self-reported Pre-pregnancy Weight (lb)	Weight (lb)	Stature (mm)	Heel Height (mm)	Arm Reach (mm)	Arm Length (mm)	Forearm Length (mm)	Sitting Height (mm)	PSIS Height (mm)	Knee Height (mm)	Popliteal Height (mm)	Buttock-Knee Length (mm)	Buttock-Popliteal Length (mm)	Hip Breadth (mm)	ASIS Breadth (mm)	Abdomen Depth (mm)	Abdominal Circumference (mm)
F0102	18	13.3	170	173	1484	15	765	302	409	803	153	462	350	556	478	412	238	335	1180
F0103	25	10.3	115	119	1510	48	717	311	406	807	139	456	358	535	452	368	237	242	800
F0104	25	10.5	110	111	1545	26	734	338	409	823	152	479	367	535	445	371	205	214	752
F0201	31	12.0	140	138	1600	25	804	301	423	859	185	473	386	576	481	401	225	225	838
F0202	30	14.5	177	191	1575	10	735	330	404	869	130	483	327	600	509	481	258	332	1127
F0203	28	9.6	152	154	1564	12	764	323	428	874	162	480	356	546	476	407	236	263	1085
F0204	35	12.0	105	106	1578	15	772	335	425	850	160	486	364	531	453	312	214	195	792
F0301	29	8.4	120	122	1635	22	797	337	429	848	150	496	384	567	482	391	240	211	910
F0302	23	14.3	150	149	1610	21	806	349	443	879	139	485	347	576	483	366	232	272	987
F0303	36	13.5	180	180	1629	10	820	348	460	845	157	524	385	601	505	440	244	313	1052
F0304	26	15.5	115	117	1630	22	772	346	448	865	169	507	390	553	469	369	237	226	806
F0305	28	14.3	123	137	1631	26	771	349	435	854	163	503	423	594	503	375	206	213	815
F0401	26	14.3	150	154	1670	39	783	340	444	900	203	511	400	580	481	391	204	246	795
F0403	30	13.4	185	194	1657	23	813	350	452	881	169	508	366	616	523	425	243	324	1175
F0404	29	9.4	125	127	1653	9	841	357	453	875	155	503	385	576	472	359	223	231	720
F0405	25	13.4	145	153	1640	14	827	355	444	884	149	510	382	600	498	401	192	241	883
F0406	32	13.2	120	122	1660	15	812	358	458	848	140	507	383	595	500	350	215	227	855
F0501	36	13.6	147	172	1691	14	750	337	453	894	176	531	444	625	548	443	269	274	895
F0502	36	14.3	140	144	1759	23	841	379	464	891	161	560	472			377	249	233	920
F0503	29	15.5	140	145	1699	34	786	369	448	910	191	525	438	595	519	405	246	214	830
F0504	25	11.1	150	159	1718	27	819	379	447	916	184	514	444	622	491	435	242	224	835
F0505	25	14.6	121	124	1671	23	781	341	435	896	143	499	398	549	464	385	223	214	843

Table E2

Subject Anthropometry Measured at All Test Sessions

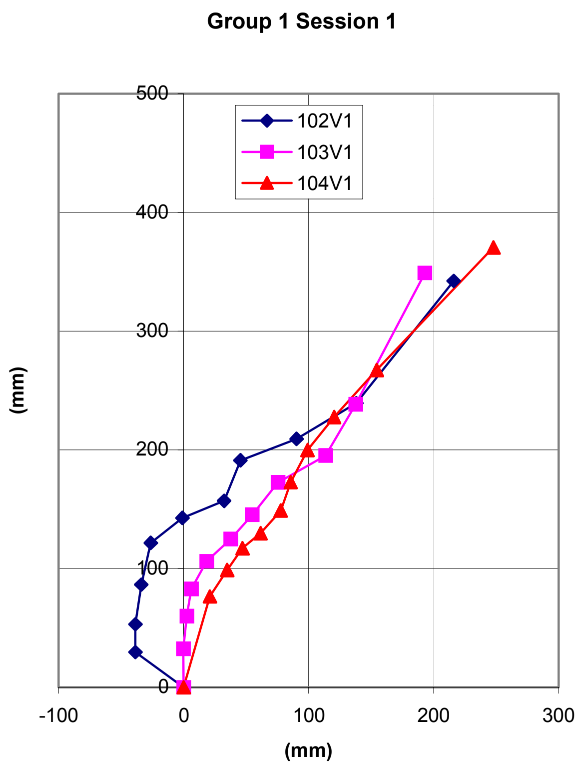
Subject	Test Session	Gestational Age (weeks)	Weight (lb)	Stature (mm)	Heel Height (mm)	Buttock-Knee Length (mm)	Buttock-Popliteal Length (mm)	Hip Breadth (mm)	ASIS Breadth (mm)	Abdomen Depth (mm)	Fundal Height (mm)	Abdominal Circumference (mm)
F0102	1	13.3	173	1484	15	556	478	412	238	335		1180
F0102	2	20.5	182	1495	15	565	490	422	228	350	180	1245
F0102	3	30.2	189	1487	33	565	491	395	236	383	270	1310
F0102	4	37.5	206	1502	15	563	479	426	253	417	385	1326
F0103	1	10.3	119	1510	48	535	452	368	237	242		800
F0103	2	20.2	125	1518	48	533	443	371	205	249	190	840
F0103	3	31.2	135	1515	48	536	470	366	203	300	285	942
F0103	4	37.0	138	1515	48	538	470	372	193	316	352	1031
F0104	1	10.5	111	1545	26	535	445	371	205	214		752
F0104	2	21.5	120	1539	28	540	462	377	201	259	210	845
F0104	3	28.6	126	1556	24	543	452	381	218	267	305	902
F0104	4	36.6	137	1553	24	545	457	393	225	302	345	1015
F0201	1	12.0	138	1600	25	576	481	401	225	225		838
F0201	2	21.5	146	1597	18	561	471	412	228	279	225	1025
F0201	3	30.0	156	1600	18	561	471	417	225	327	315	1090
F0201	4	37.0	154	1598	18	567	470	427	263	352	391	1114
F0202	1	14.5	191	1575	10	600	509	481	258	332		1127
F0202	2	22.2	203	1567	25	617	520	511	261	357	220	1215
F0202	3	28.2	213	1559	32	612	527	500	271	378	285	1175
F0202	4	35.5	222	1556	18	623	524	530	289	287	375	1230
F0203	1	9.6	154	1564	12	546	476	407	236	263		1085
F0203	2	21.2	164	1567	10	545	475	412	241	300	195	1100
F0203	3	28.1	171	1556	21	549	461	410	241	314	255	1045
F0203	4	37.1	185	1568	21	557	486	424	248	362	365	1175
F0204	1	12.0	106	1578	15	531	453	312	214	195		792
F0204	2	20.1	118	1578	46	522	420	327	220	250	210	865
F0204	3	29.1	131	1590	15	534	474	336	225	278	306	971
F0204	4	37.5	136	1591	60	535	440	361	224	323	370	1015
F0301	1	8.4	122	1635	22	567	482	391	240	211		910
F0301	2	21.4	134	1631	10	584	495	392	260	254	195	925
F0301	3	32.1	145	1624	22	578	485	404	267	281	315	958
F0301	4	36.4	150	1638	10	582	513	408	263	301	350	990
F0302	1	14.3	149	1610	21	576	483	366	232	272		987
F0302	2	23.2	160	1600	10	582	482	393	235	307	230	1060
F0302	3	29.1	163	1595	10	575	497	382	250	311	285	1035
F0302	4	36.6	178	1608	10	575	485	408	260	326	360	1055
F0303	1	13.5	180	1629	10	601	505	440	244	313		1052
F0303	2	23.0	183	1623	10	595	508	417	266	339	260	1097
F0303	3	29.0	190	1625	10	608	510	446	286	335	320	1125
F0303	4	36.4	200	1633	10	595	515	446	287	376	410	1215
F0304	1	15.5	117	1630	22	553	469	369	237	226		806
F0304	2	21.5	124	1627	22	566	463	367	251	233	215	817
F0304	3	29.5	129	1630	23	572	489	389	253	264	250	933
F0304	4	36.1	136	1630	22	564	492	378	262	287	302	970
F0305	1	14.3	137	1631	26	594	503	375	206	213		815
F0305	2	24.6	147	1634	31			385	200	280	235	963
F0305	3	31.5	156	1633	32	596	493	403	225	308	285	1010
F0305	4	38.3	163	1637	32	600	486	414	195	322	320	1035

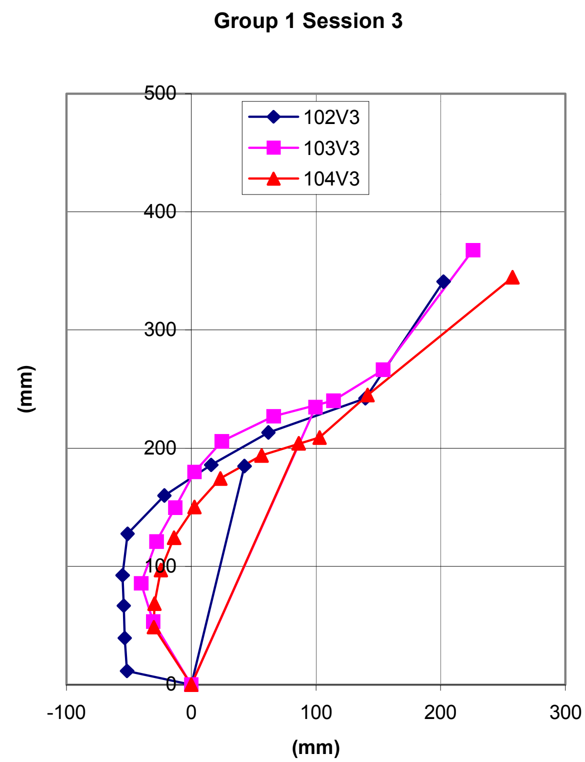
Table E2

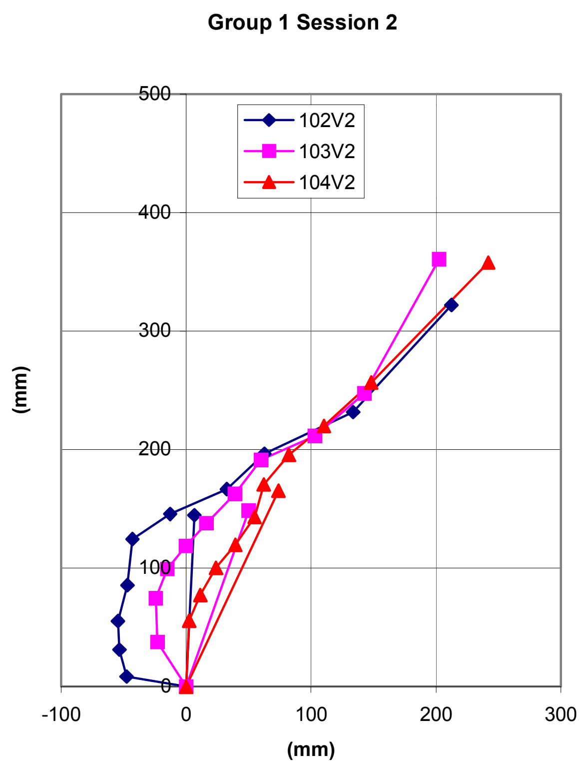
Subject Anthropometry Measured at All Test Sessions

Subject	Test Session	Gestational Age (weeks)	Weight (lb)	Stature (mm)	Heel Height (mm)	Buttock-Knee Length (mm)	Buttock-Popliteal Length (mm)	Hip Breadth (mm)	ASIS Breadth (mm)	Abdomen Depth (mm)	Fundal Height (mm)	Abdominal Circumference (mm)
F0401	1	14.3	154	1670	39	580	481	391	204	246		795
F0401	2	24.4	165	1672	32			407	223	288	250	1016
F0401	3	29.5	175	1665	32	588	476	424	217	315	315	1035
F0401	4	35.5	183	1660	42	588	481	436	212	365	385	1120
F0403	1	13.4	194	1657	23	616	523	425	243	324		1175
F0403	2	23.1	204	1652	22	613	495	416	269	341	220	1248
F0403	3	30.1	208	1654	22	608	517	431	257	377	295	1267
F0403	4	38.4	216	1672	22	604	513	434	291	404	380	1315
F0404	1	9.4	127	1653	9	576	472	359	223	231		720
F0404	2	22.4	138	1645	9	584	475	362	215	269	270	960
F0404	3	29.4	145	1648	10	577	505	358	230	310	290	1010
F0404	4	37.4	162	1649	10	585	492	386	262	333	430	1090
F0405	1	13.4	153	1640	14	600	498	401	192	241		883
F0405	2	22.6	167	1655	14	604	515	400	220	292	260	1045
F0405	3	30.3	175	1643	28	597	512	432	220	293	310	1045
F0405	4	37.0	187	1645	14	609	504	426	218	350	430	1120
F0406	1	13.2	122	1660	15	595	500	350	215	227		855
F0406	2	22.2	126	1659	15	590	495	340	219	261	185	923
F0406	3	29.2	131	1667	25	591	483	338	213	272	280	975
F0406	4	37.2	137	1678	35	592	494	352	226	314	370	1005
F0501	1	13.6	172	1691	14	625	548	443	269	274		895
F0501	2	21.5	179	1686	30			443	258	304	215	985
F0501	3	29.5	196	1679	30	632	535	457	259	365	315	1142
F0501	4	36.6	209	1675	11	642	552	497	282	408	375	1240
F0502	1	14.3	144	1759	23			377	249	233		920
F0502	2	21.2	154	1763	33	623		390	251	249	200	970
F0502	3	28.4	161	1769	18	619	536	395	253	288	245	1007
F0502	4	35.4	168	1765	25	623	520	396	262	309	320	1045
F0503	1	15.5	145	1699	34	595	519	405	246	214		830
F0503	2	22.0	156	1699	28	593	507	431	256	245	205	960
F0503	3	29.5	172	1688	26	614	518	436	269	307	290	1045
F0503	4	36.6	182	1689	27	608	513	445	265	335	350	1100
F0504	1	11.1	159	1718	27	622	491	435	242	224		835
F0504	2	21.6	168	1725	24	618	506	416	224	284	204	1015
F0504	3	31.4	181	1722	26	640	521	436	250	349	320	1235
F0504	4	37.4	185	1720	18	620	519	405	264	380	355	1185
F0505	1	14.6	124	1671	23	549	464	385	223	214		843
F0505	2	19.4	132	1672	23	547	464	373	237	259	210	895
F0505	3	28.1	142	1666	17	572	481	388	237	268	260	965
F0505	4	36.5	148	1652	27	580	482	370	243	310	365	1065

Appendix F
Individual Abdomen Contours







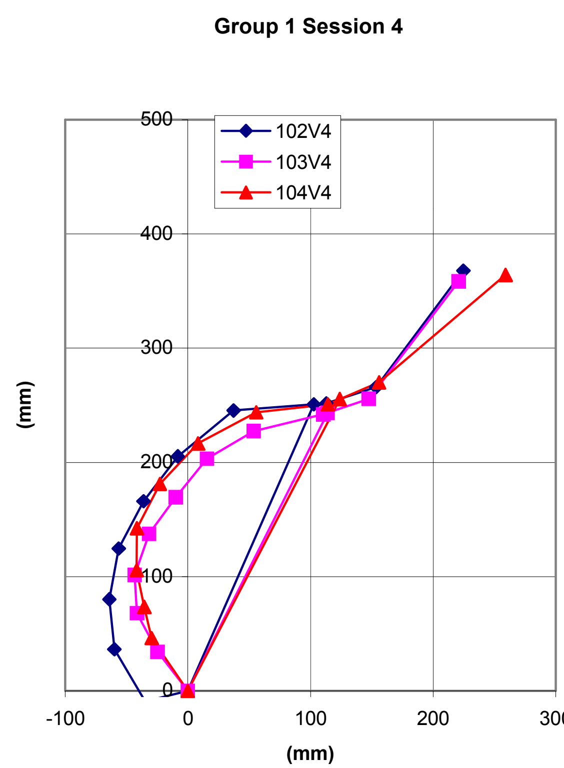


Figure F.1. Abdomen contours for Group-1 subjects at each test session.

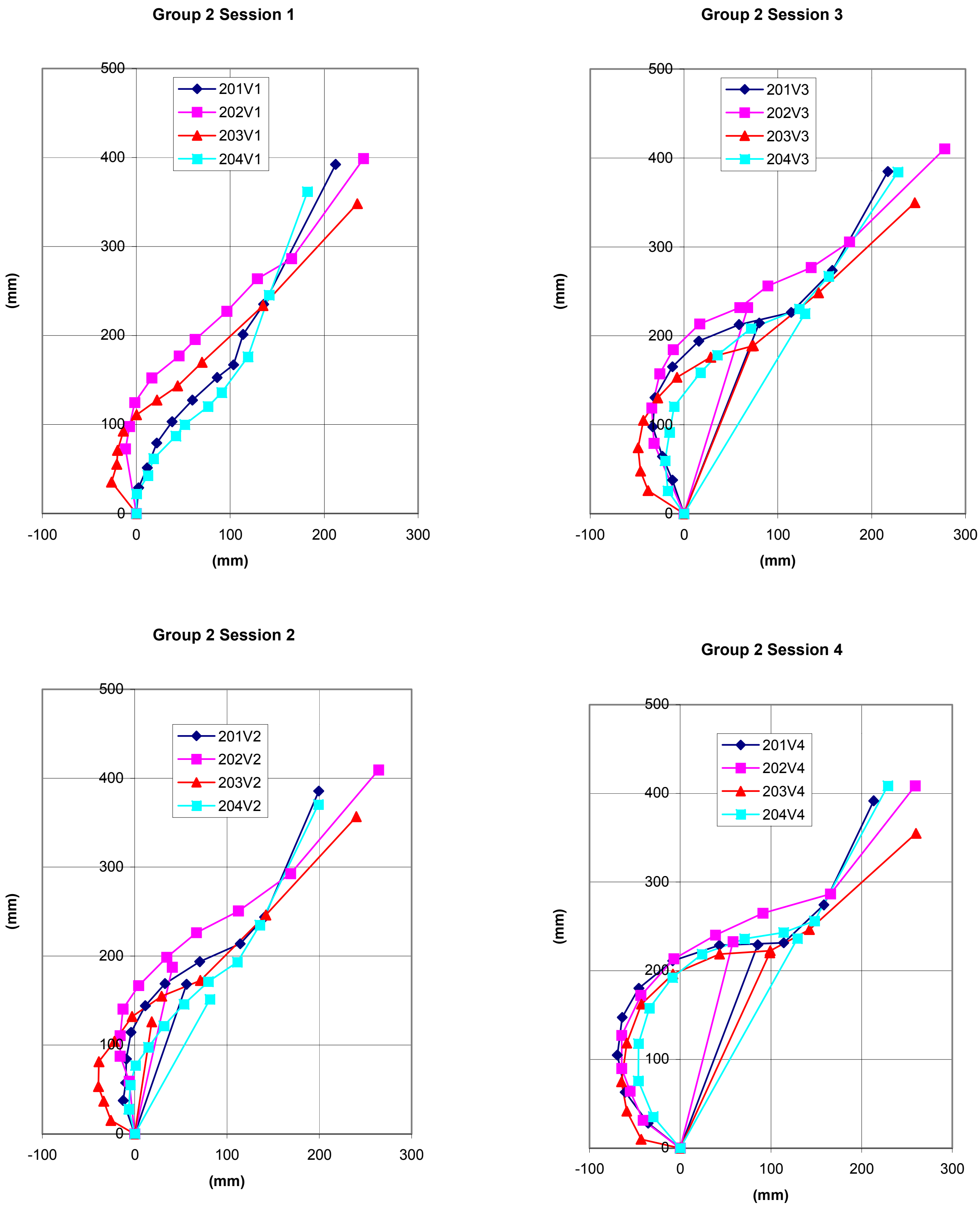


Figure F.2. Abdomen contours for Group-2 subjects at each test session.

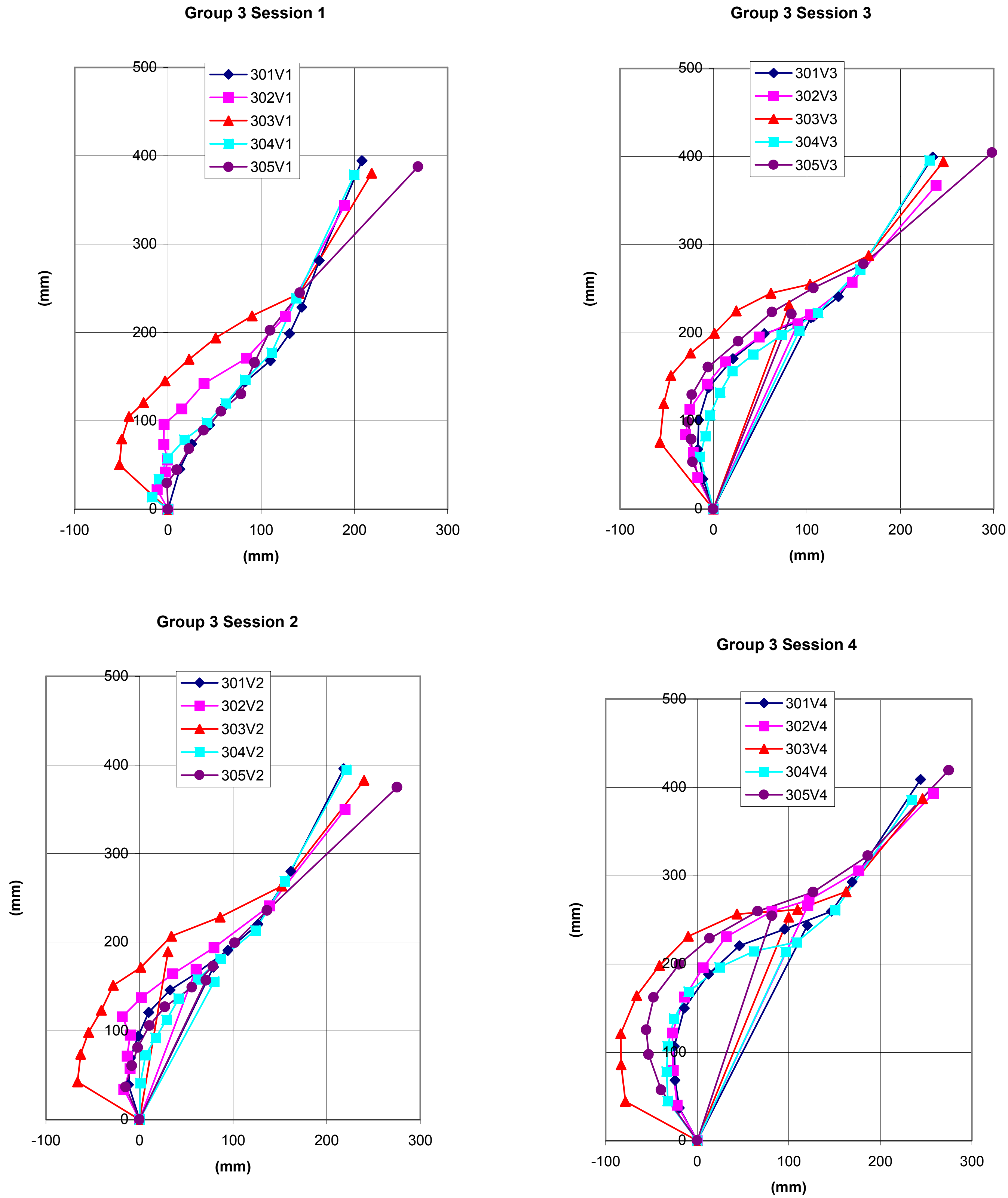


Figure F.3. Abdomen contours for Group-3 subjects at each test session.

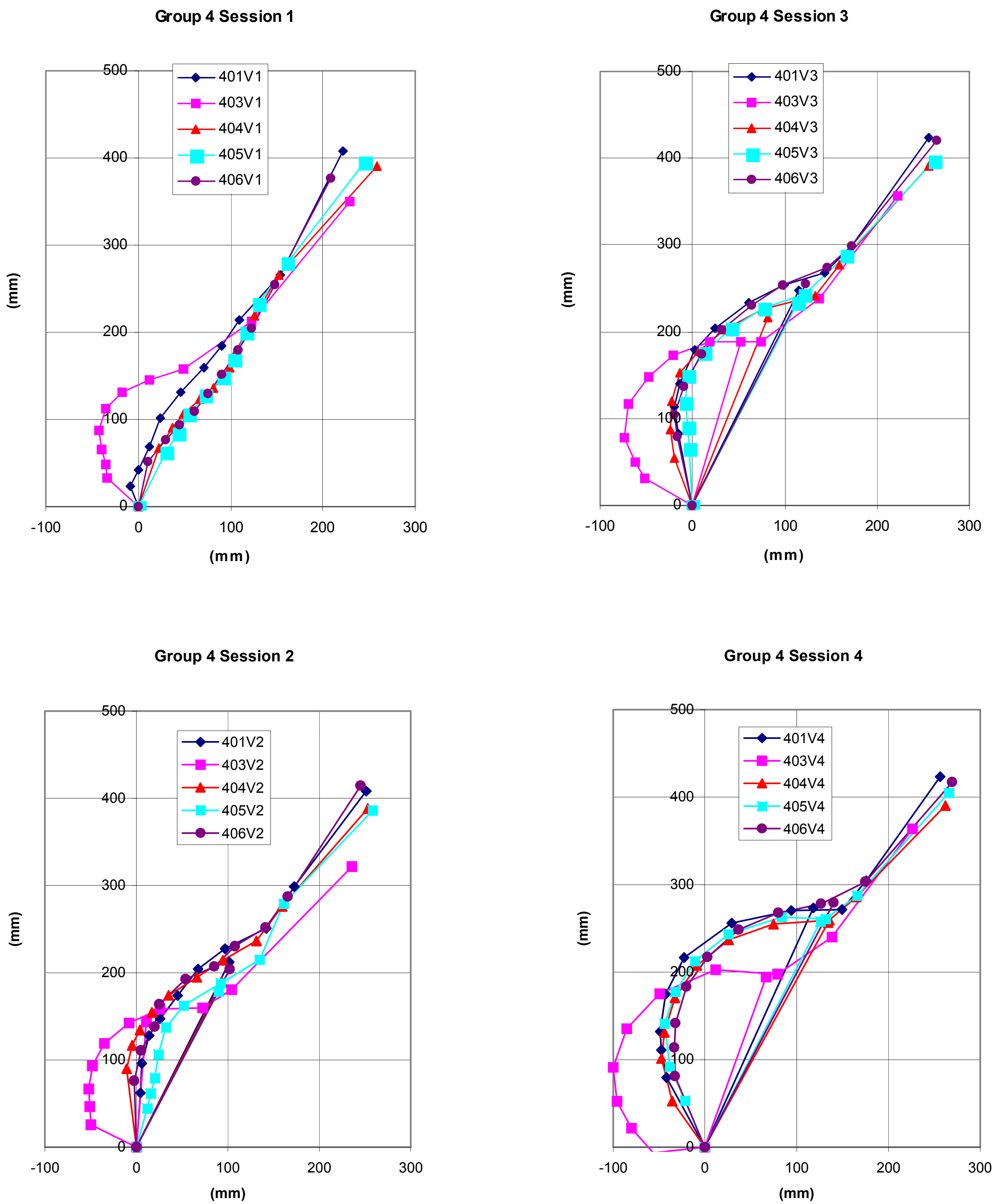


Figure F.4. Abdomen contours for Group-4 subjects at each test session.

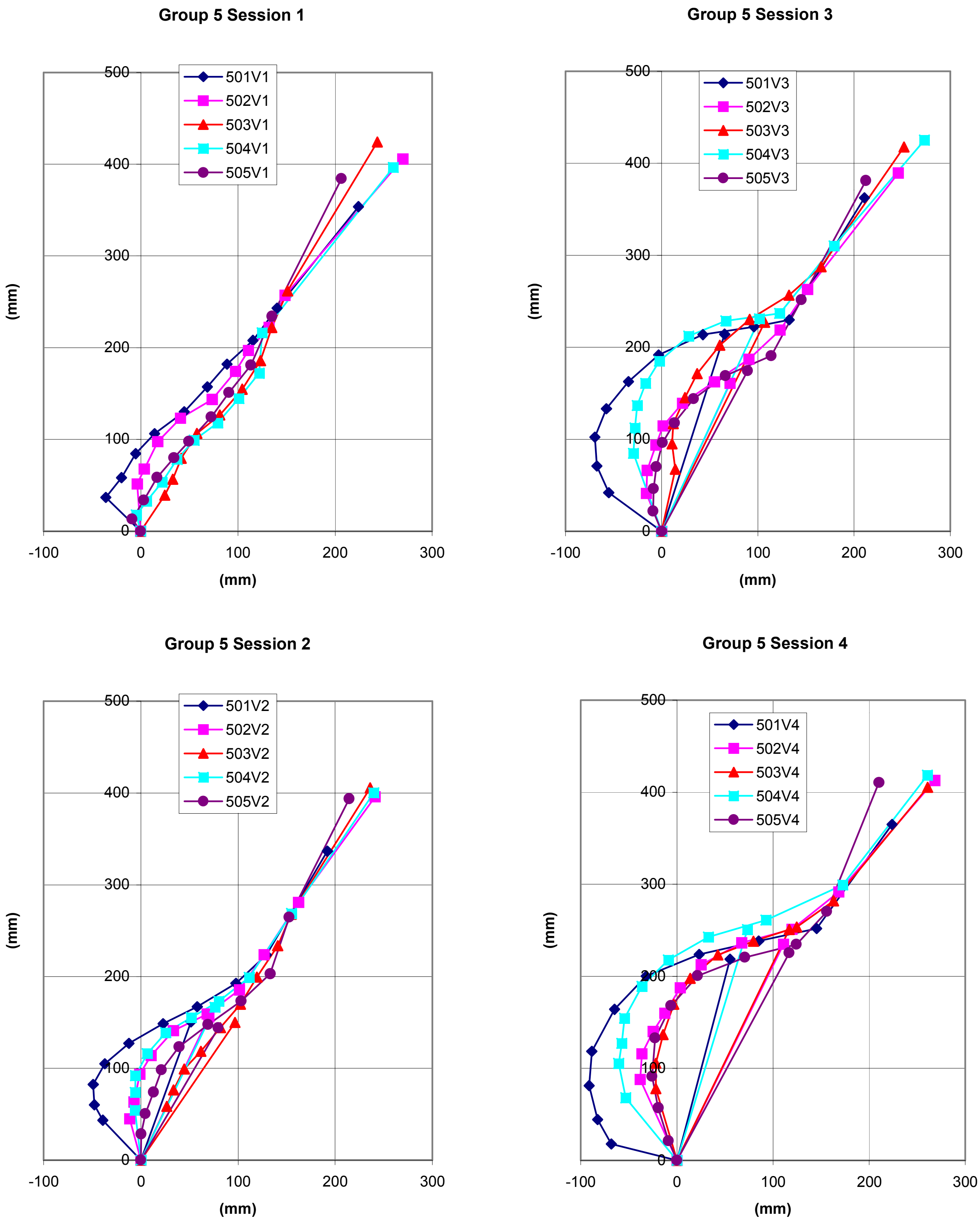


Figure F.5. Abdomen contours for Group-5 subjects at each test session.

Appendix G
Average Seated Postures and Abdomen Contours

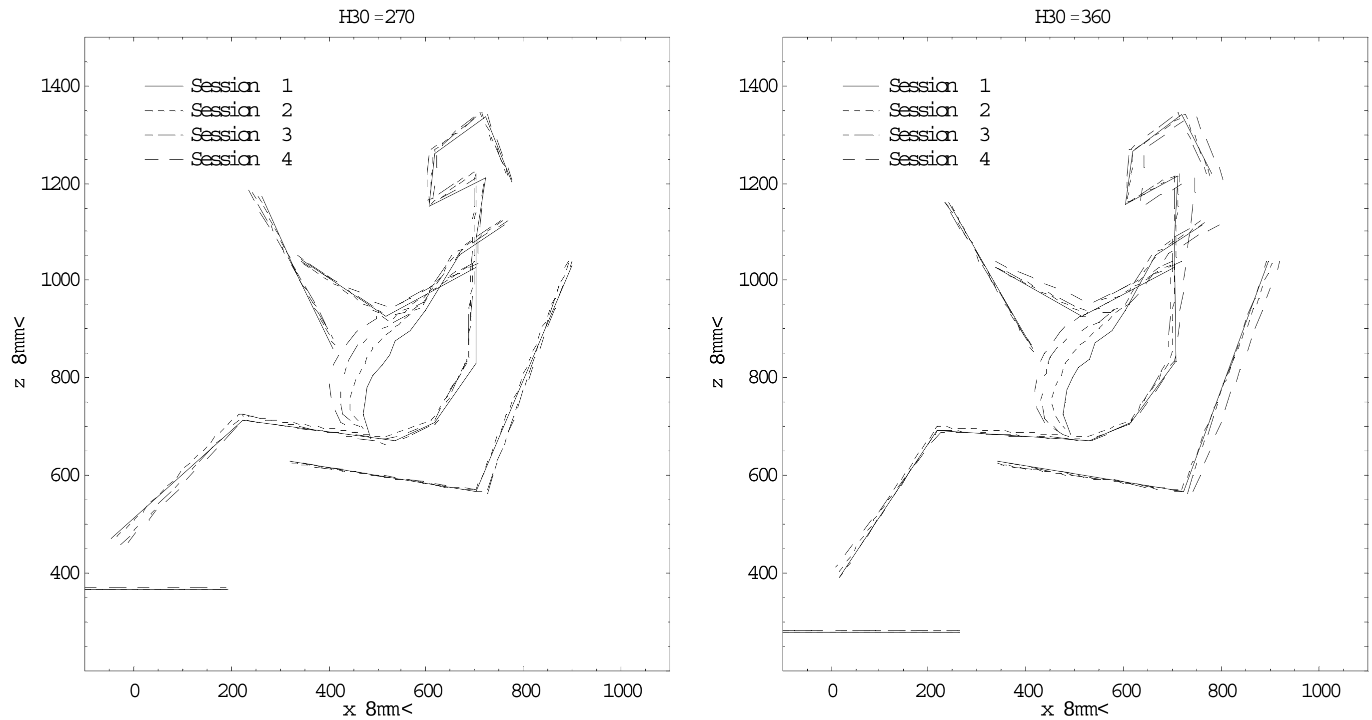


Figure G.1. Average postures and abdomen contours of Group-1 subjects for each gestational age and seat height.

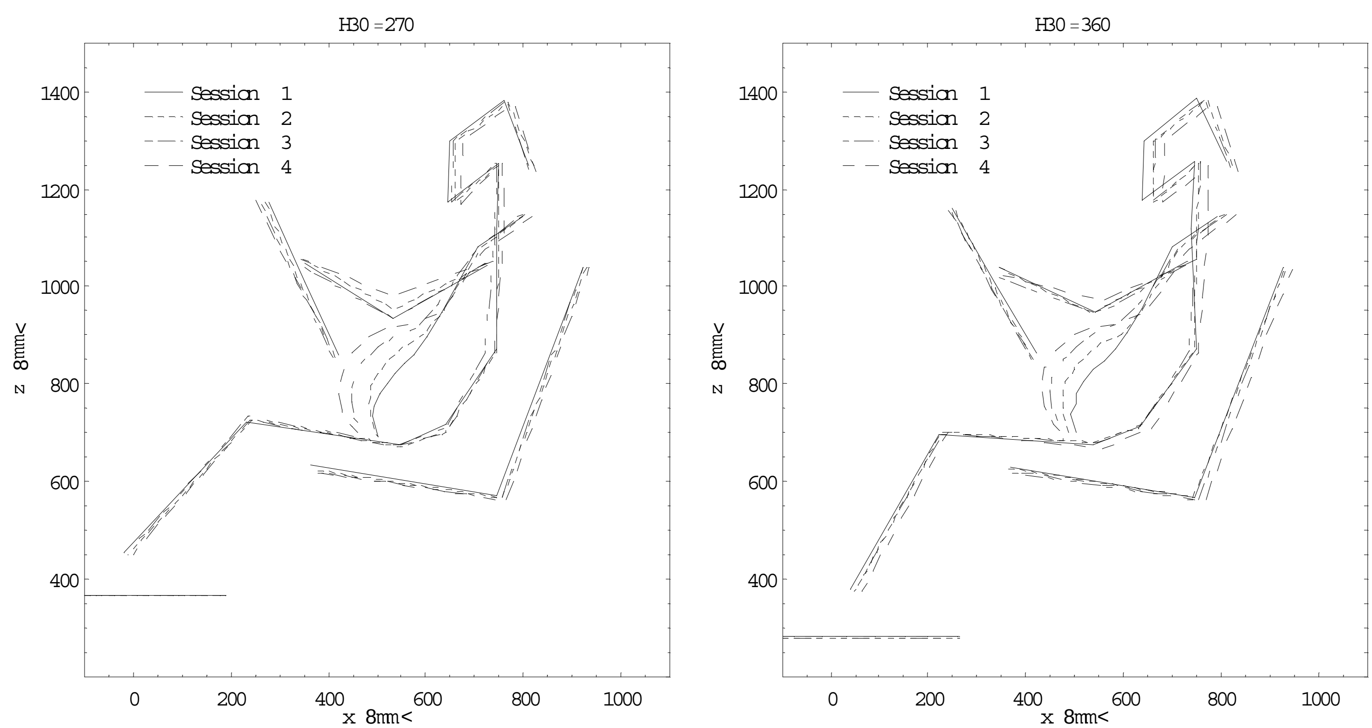


Figure G.2. Average postures and abdomen contours of Group-2 subjects for each gestational age and seat height.

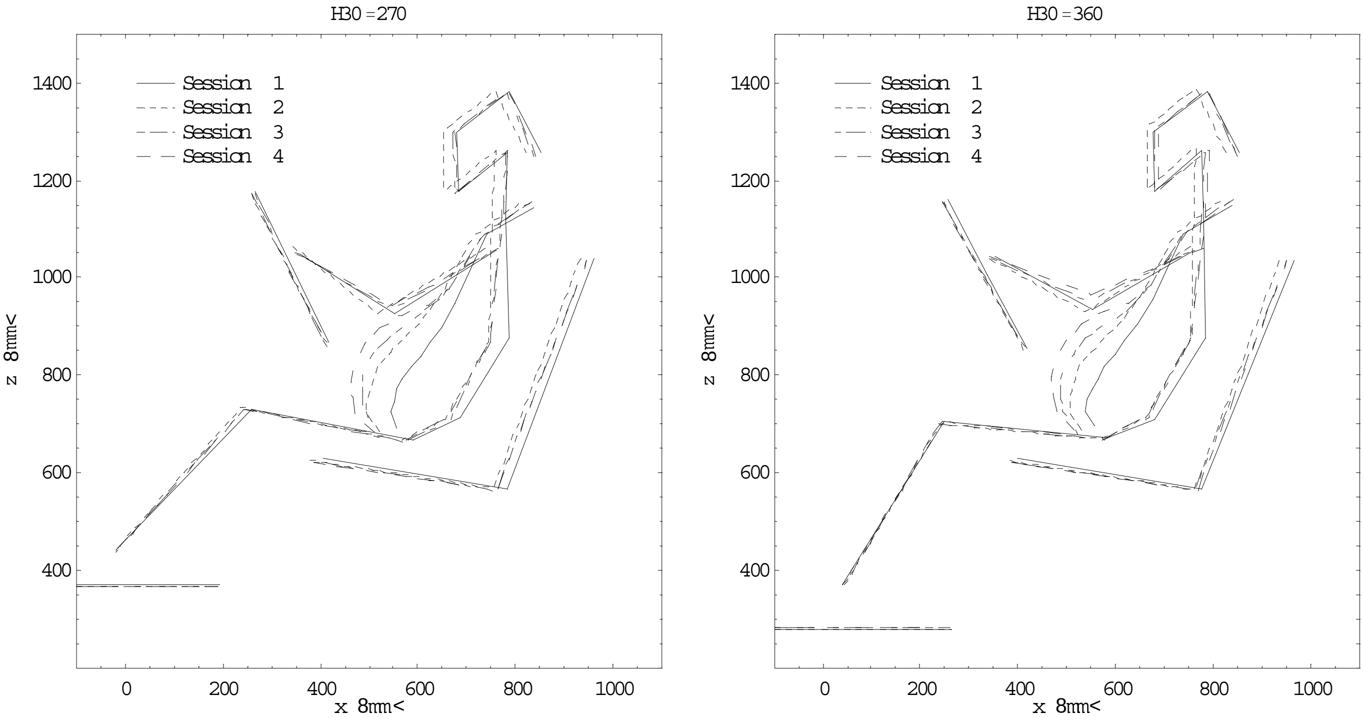


Figure G.3. Average postures and abdomen contours of Group-3 subjects for each gestational age and seat height.

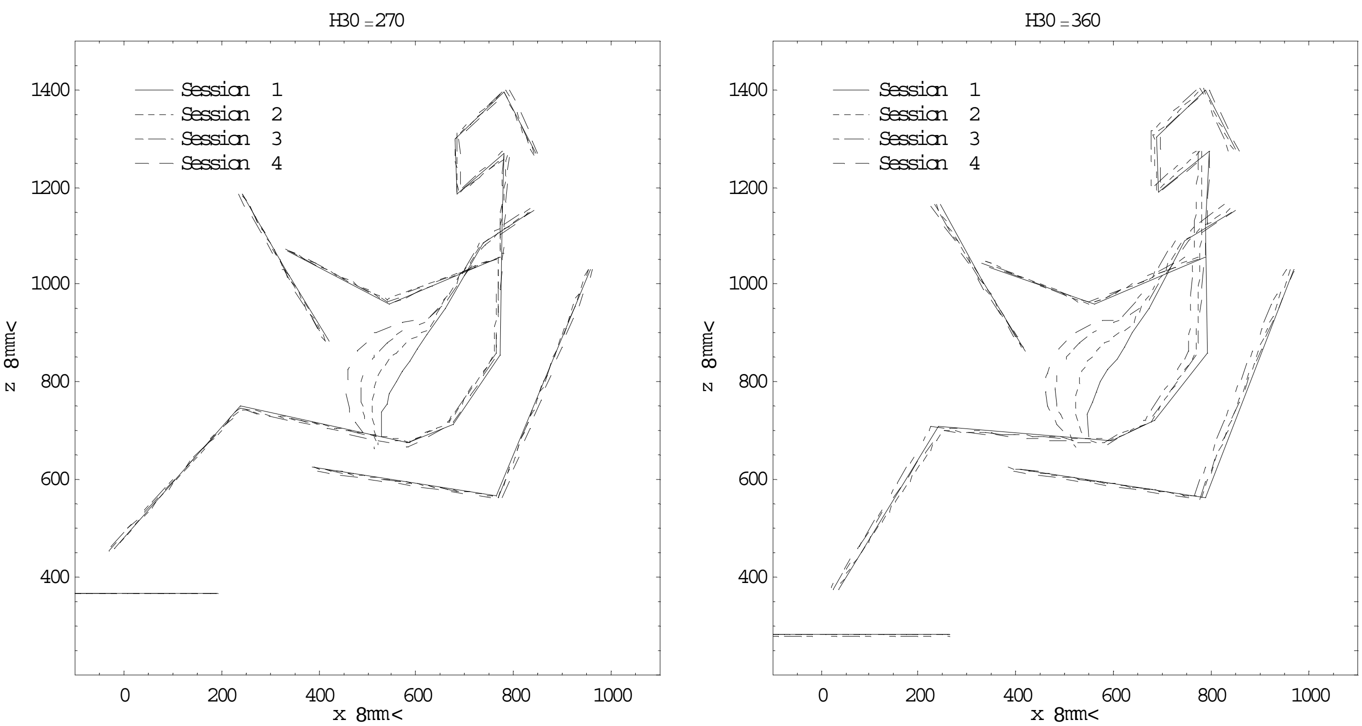


Figure G.4. Average postures and abdomen contours of Group-4 subjects for each gestational age and seat height.

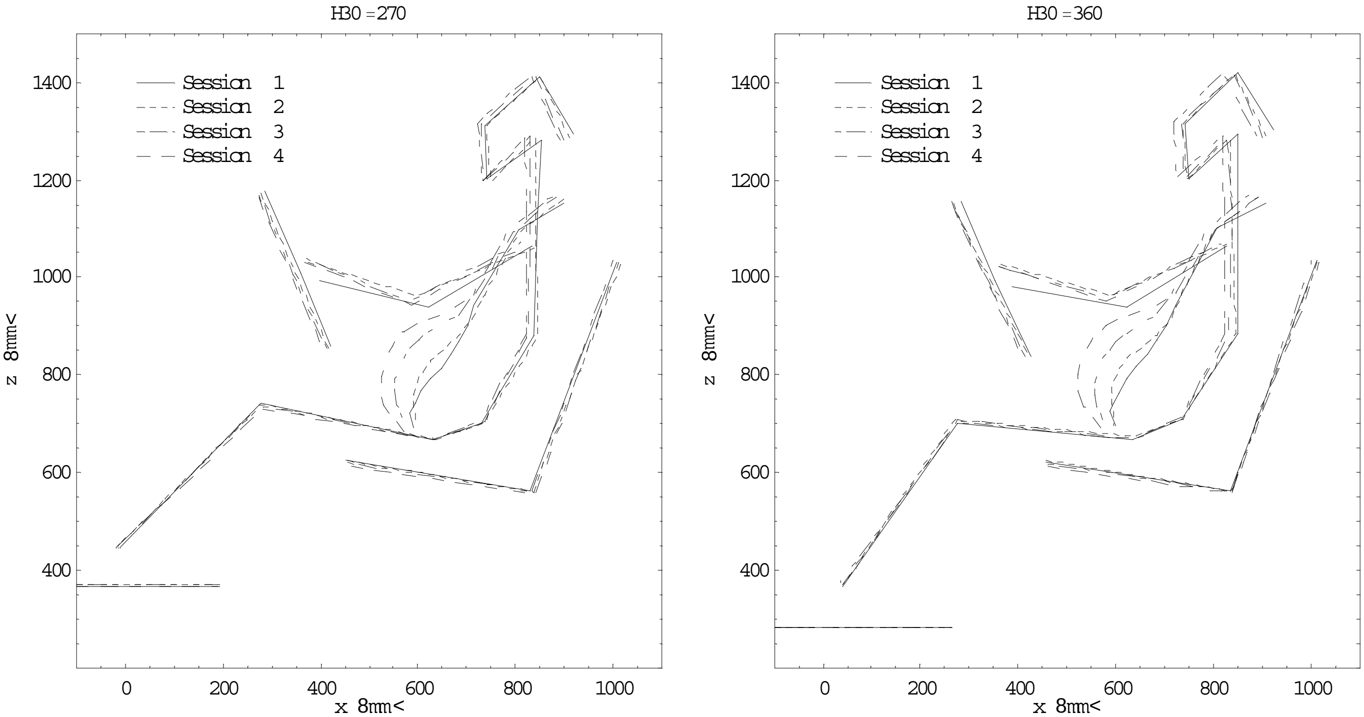
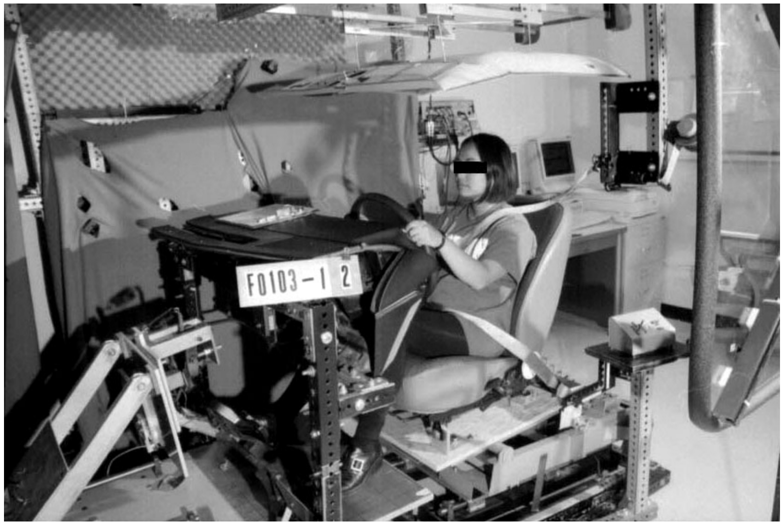
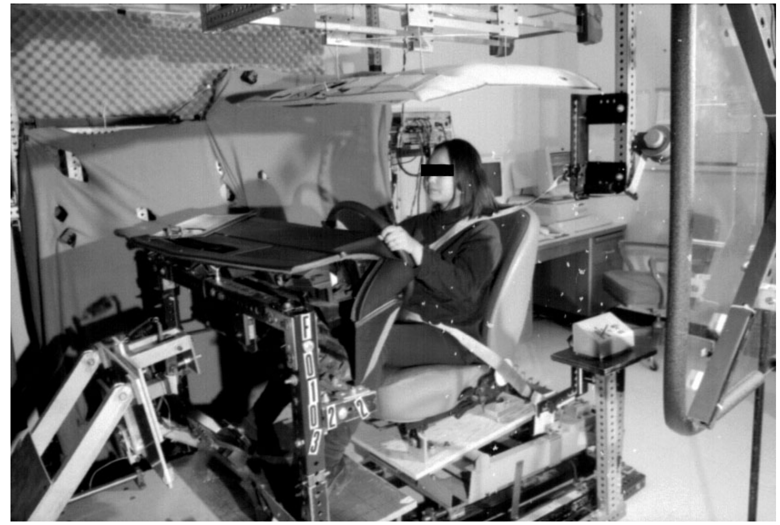


Figure G.5. Average postures and abdomen contours of Group-5 subjects for each gestational age and seat height.

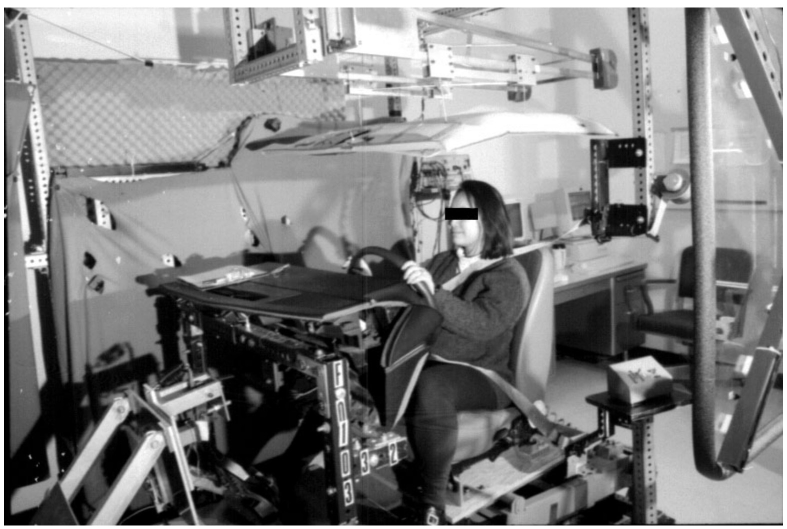
Appendix H
Selected Subject Photos in Different Test Conditions



Session 1



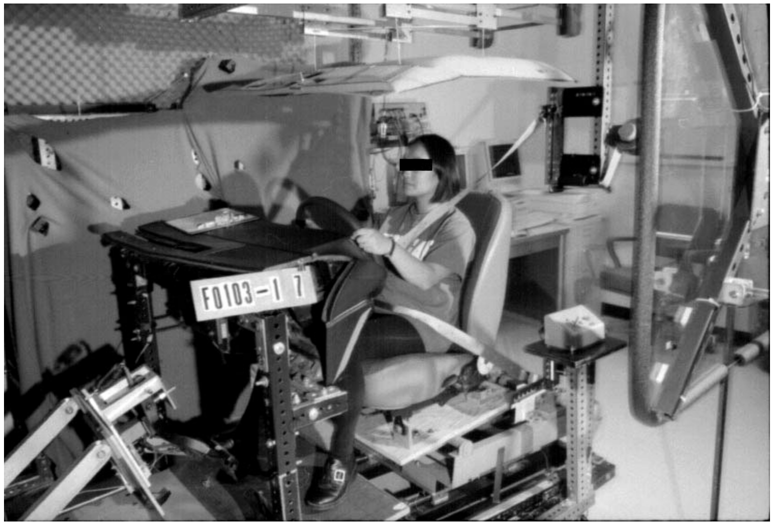
Session 2



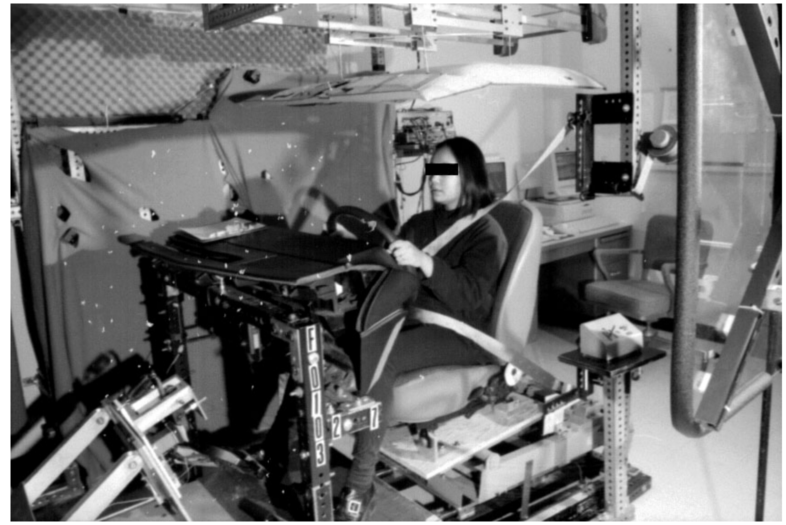
Session 3

Session 4

Figure H.1. Subject F0103 – Configuration 2 (Shoulder Belt 20° / Lap Belt 60° / 270-mm Seat Height)



Session 1



Session 2

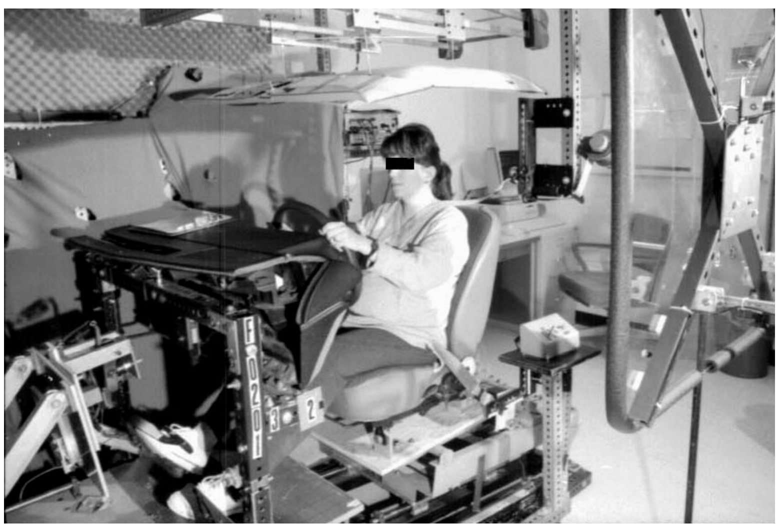
Session 3

Session 4

Figure H.2. Subject F0103 – Configuration 7 (Shoulder Belt 60° / Lap Belt 40° / 360-mm Seat Height)

Session 1

Session 2



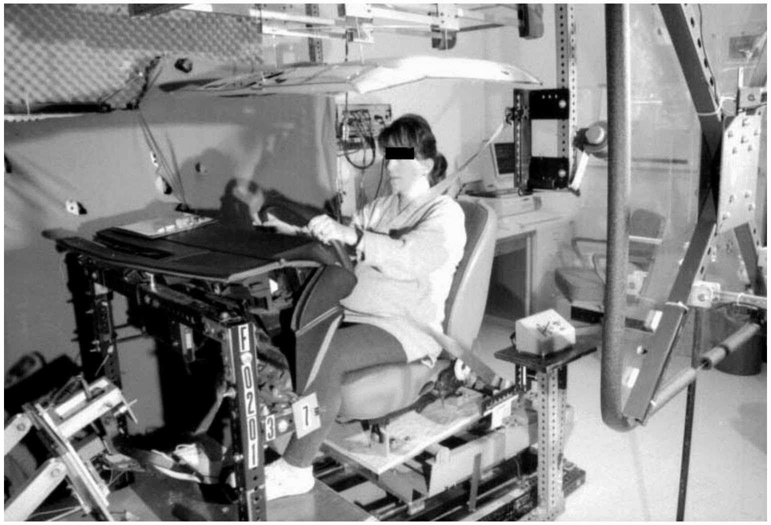
Session 3

Session 4

Figure H.3. Subject F0201 – Configuration 2 (Shoulder Belt 20° / Lap Belt 60° / 270-mm Seat Height)

Session 1

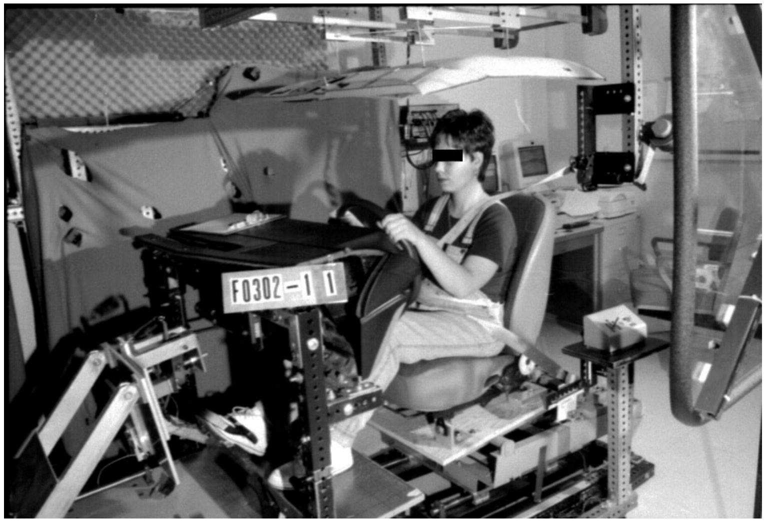
Session 2



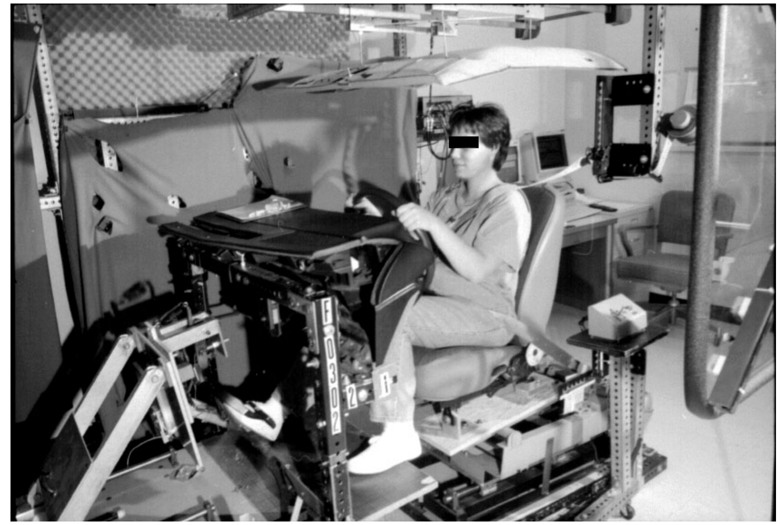
Session 3

Session 4

Figure H.4. Subject F0201 – Configuration 7 (Shoulder Belt 60° / Lap Belt 40° / 360-mm Seat Height)



Session 1

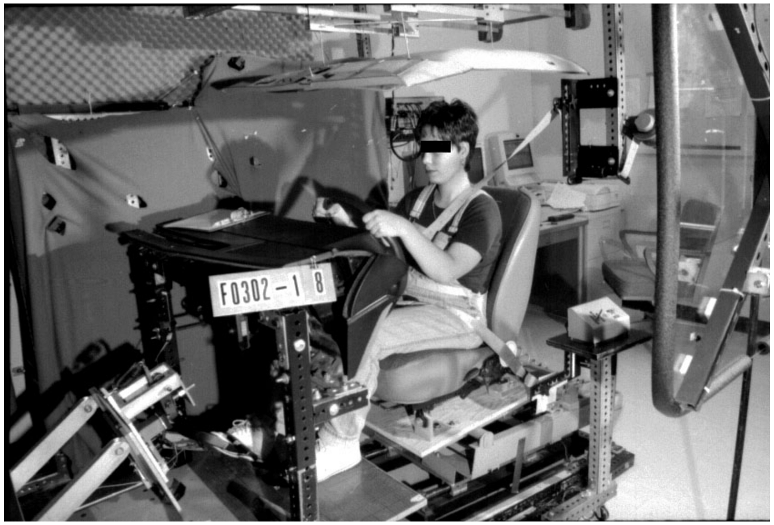


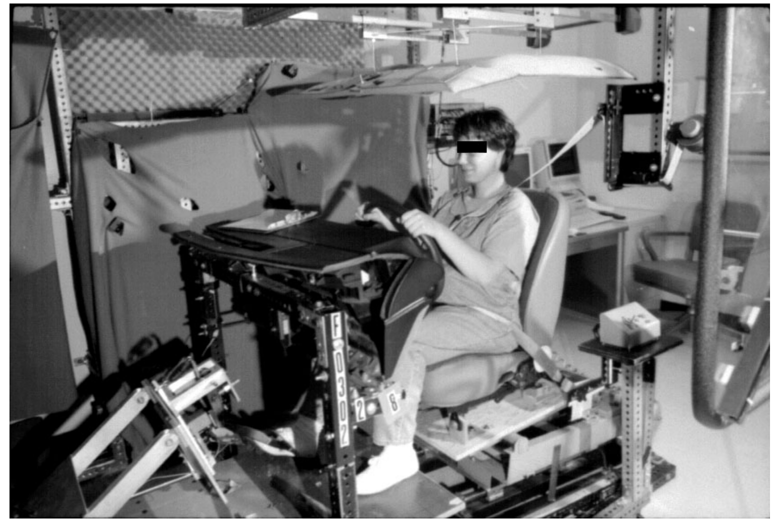
Session 2

Session 3

Session 4

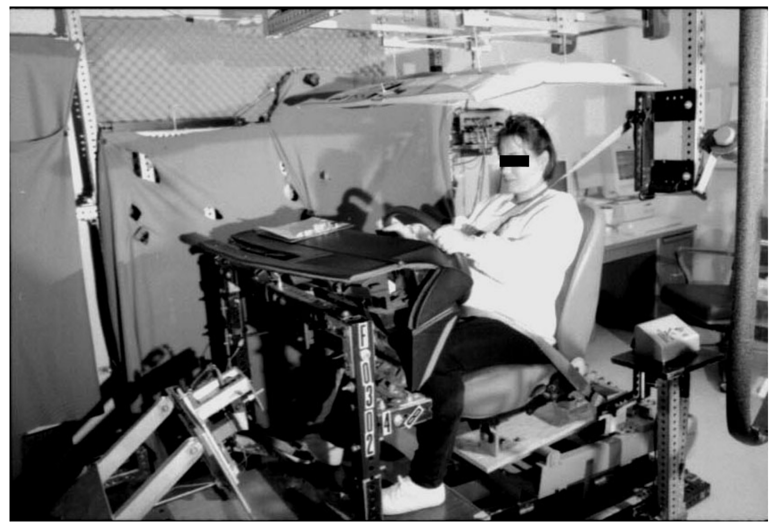
Figure H.5. Subject F0302 – Configuration 1 (Shoulder Belt 20° / Lap Belt 40° / 270-mm Seat Height)





Session 1

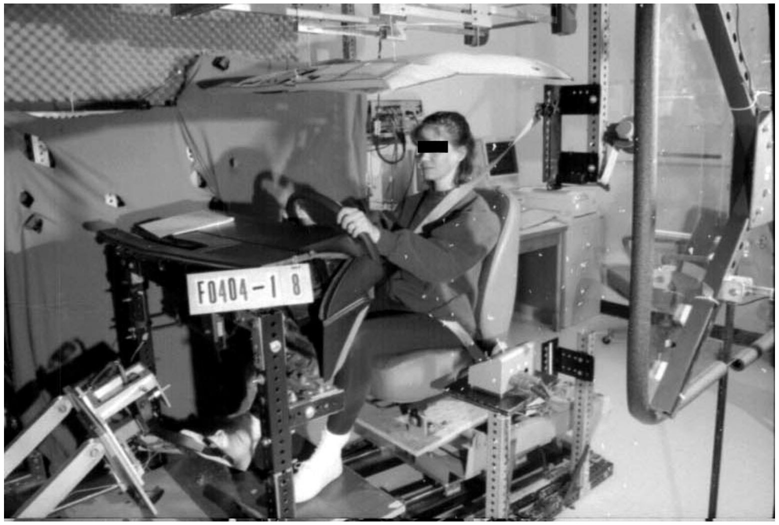
Session 2

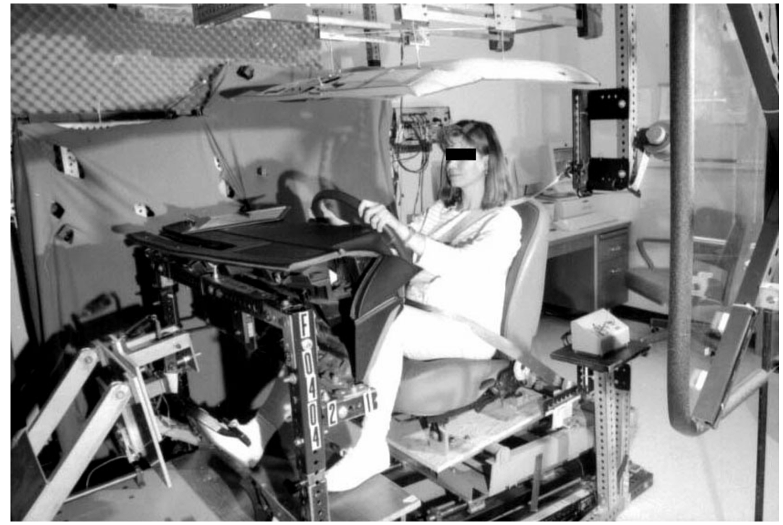


Session 3

Session 4

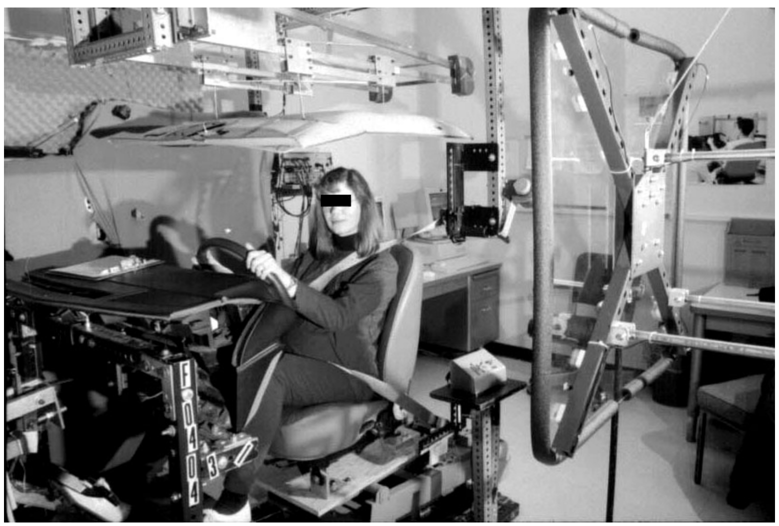
Figure H.6. Subject F0302 – Configuration 8 (Shoulder Belt 60° / Lap Belt 60° / 360-mm Seat Height)

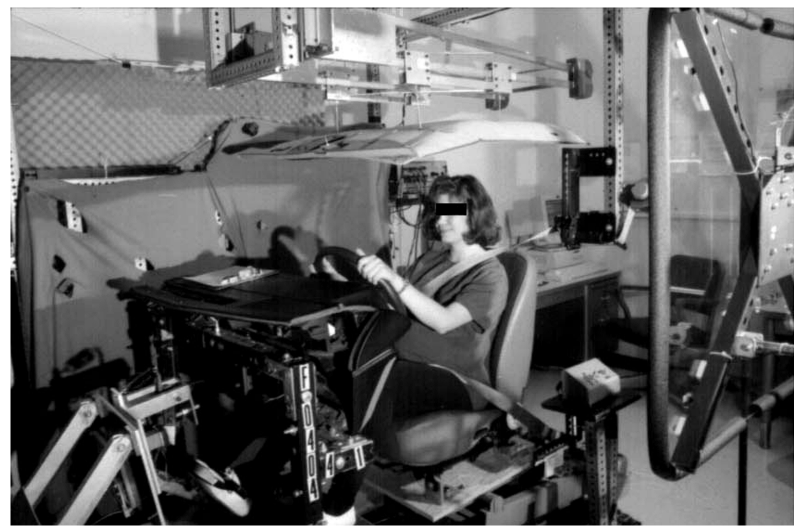




Session 1

Session 2

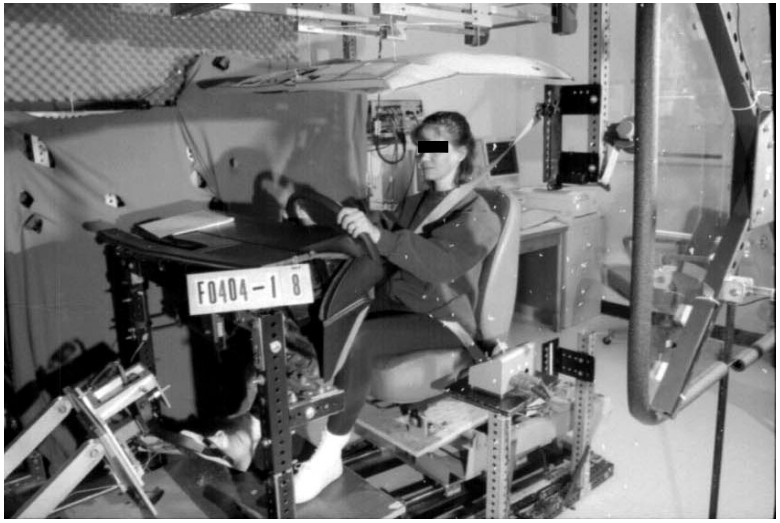




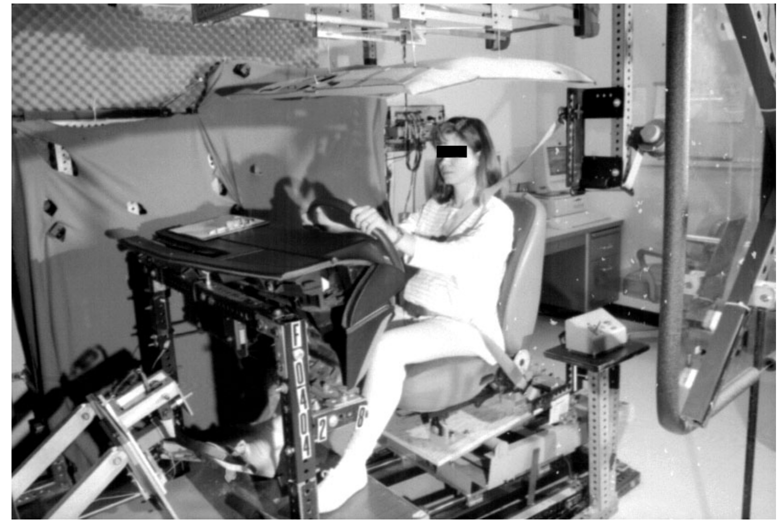
Session 3

Session 4

Figure H.7. Subject F0404 – Configuration 1 (Shoulder Belt 20° / Lap Belt 40° / 270-mm Seat Height)

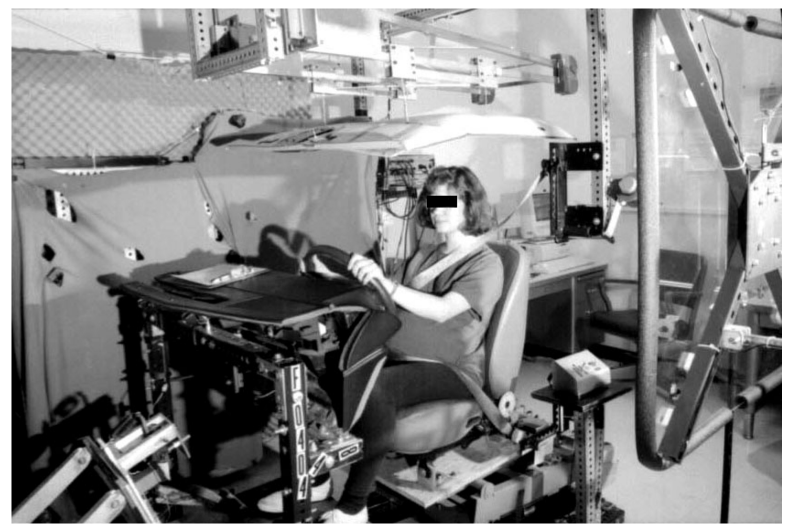


Session 1



Session 2

Session 3

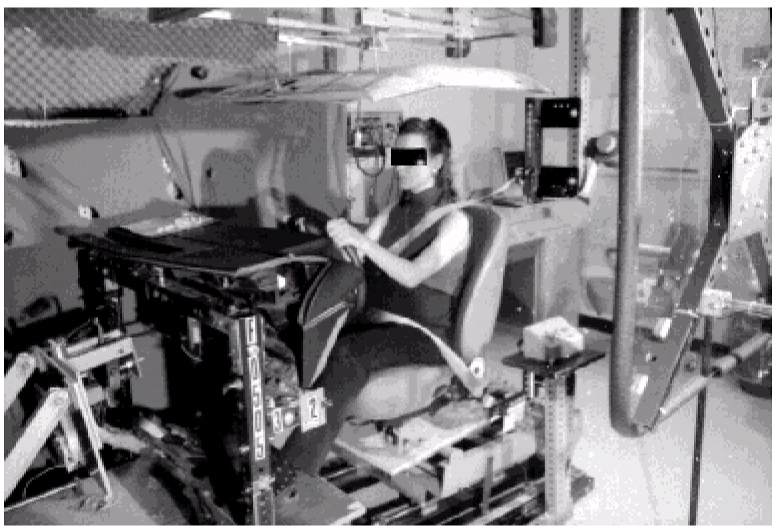


Session 4

Figure H.8. Subject F0404 – Configuration 8 (Shoulder Belt 60° / Lap Belt 60° / 360-mm Seat Height)

Session 1

Session 2



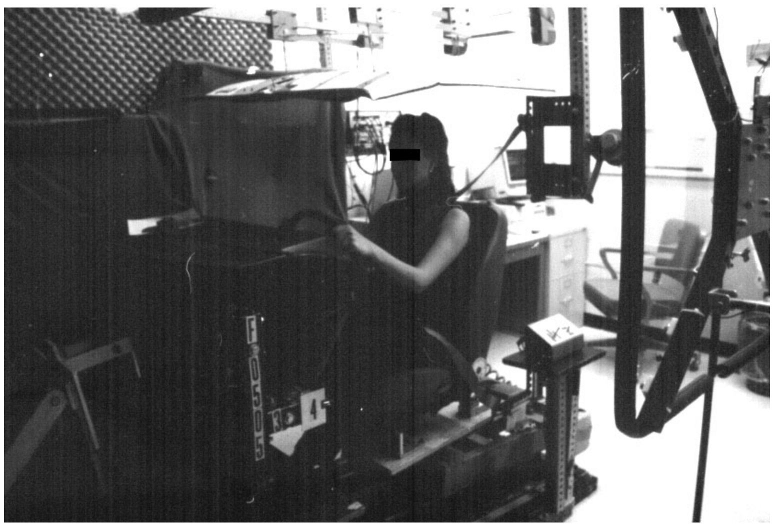
Session 3

Session 4

Figure H.9. Subject F0505 – Configuration 2 (Shoulder Belt 20° / Lap Belt 60° / 270-mm Seat Height)

Session 1

Session 2



Session 3

Session 4

Figure H.10. Subject F0505 – Configuration 7 (Shoulder Belt 60° / Lap Belt 40° / 360-mm Seat Height)

Appendix I
Photos of Subject-Selected Configurations

F0102 – 360-mm Seat Height

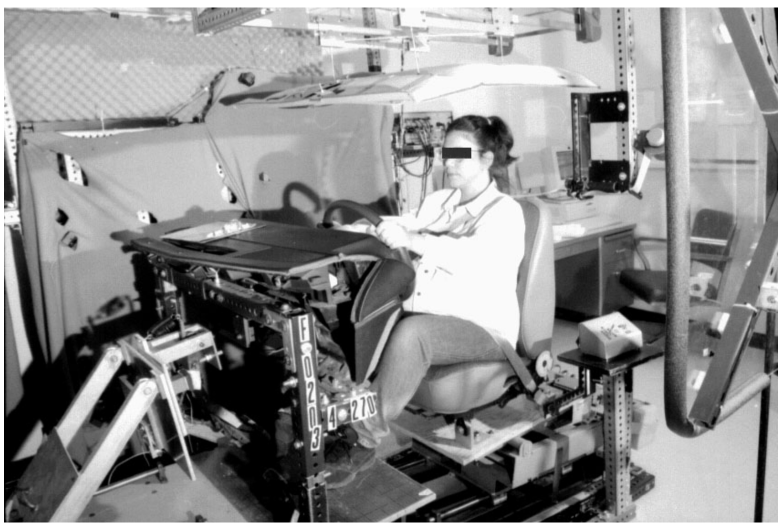
F0103 – 270-mm Seat Height

F0104 – 270-mm Seat Height

Figure I.1. Group 1 – Session 4: Subject-Selected Belt-Restraint Anchorage and Pedal Positions

F0201 – 360-mm Seat Height

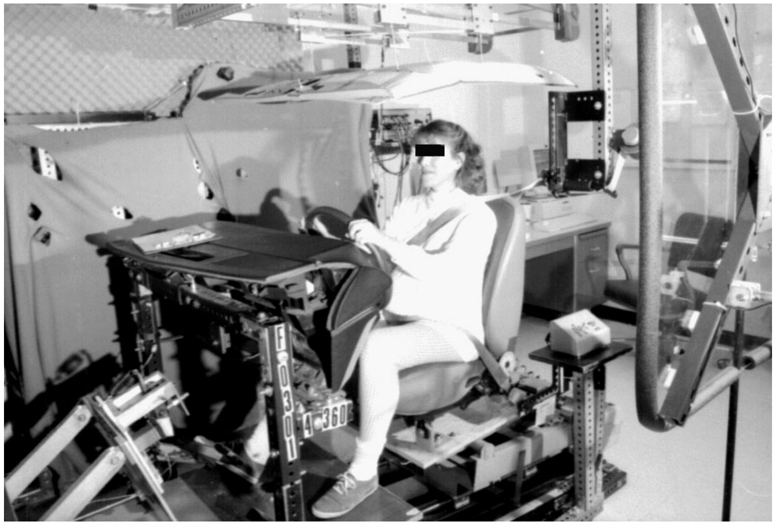
F0202 – 360-mm Seat Height



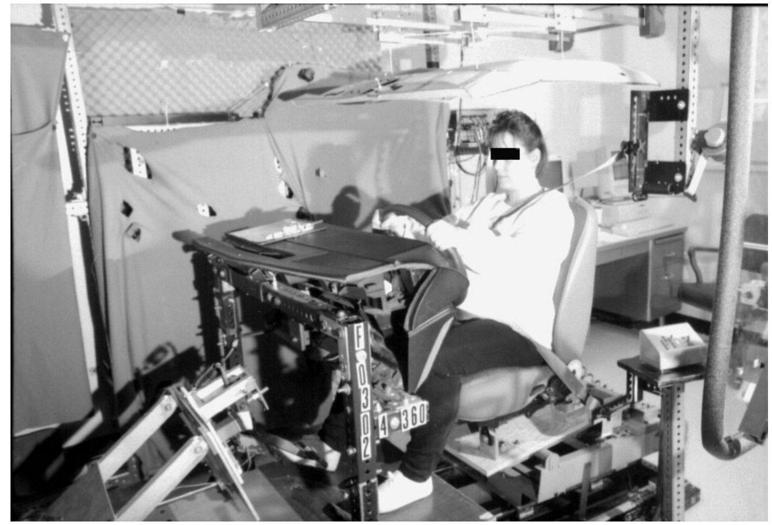
F0203 – 270-mm Seat Height

F0204 – 270-mm Seat Height

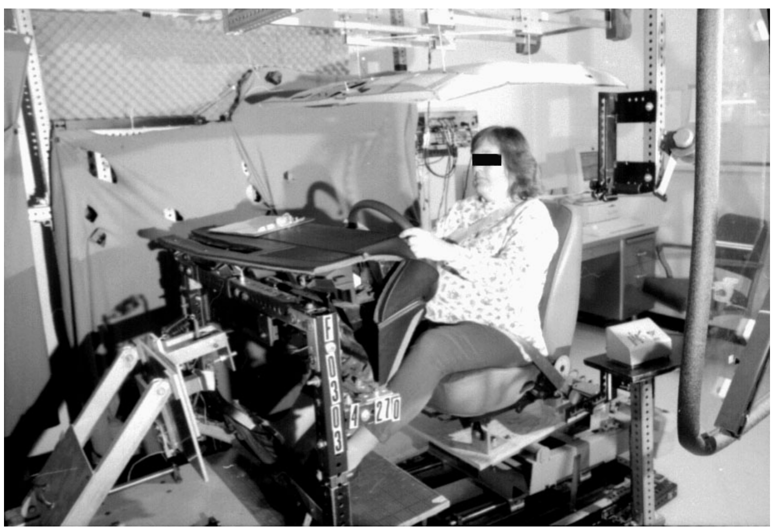
Figure I.2. Group 2 - Session 4: Subject-Selected Belt-Restraint Anchorage and Pedal Positions



F0301 – 360-mm Seat Height



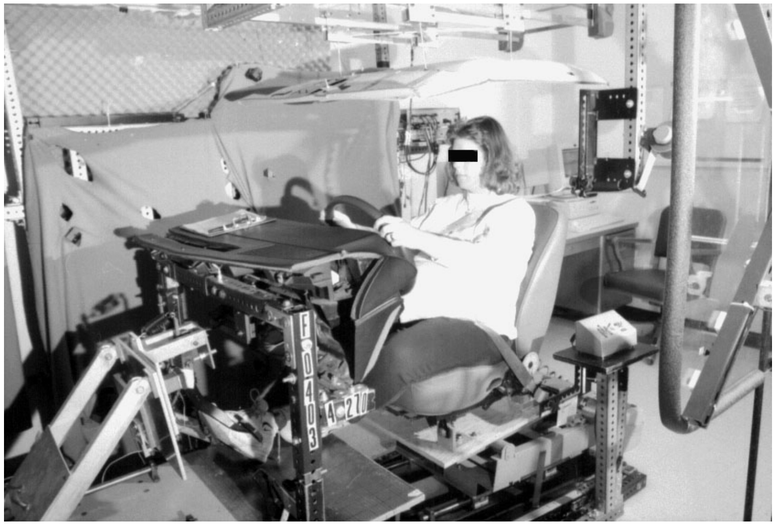
F0302 – 360-mm Seat Height



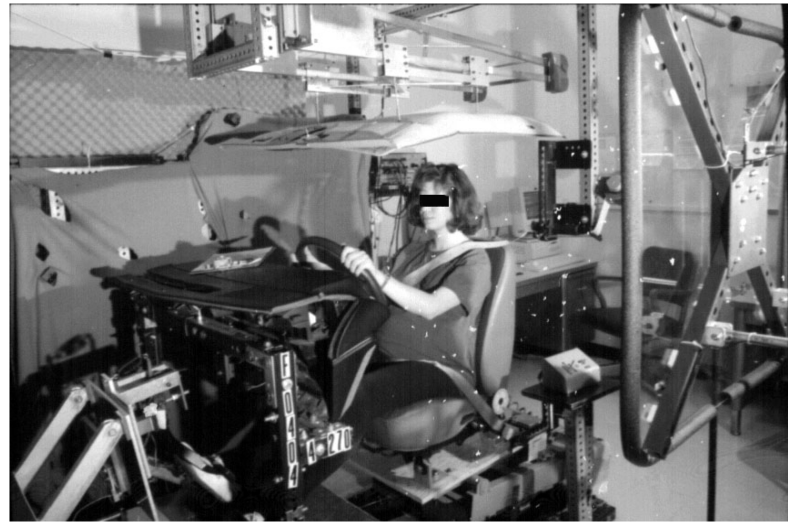
F0303 – 270-mm Seat Height

F0305 – 360-mm Seat Height

Figure I.3. Group 3 - Session 4: Subject-Selected Belt-Restraint Anchorage and Pedal Positions



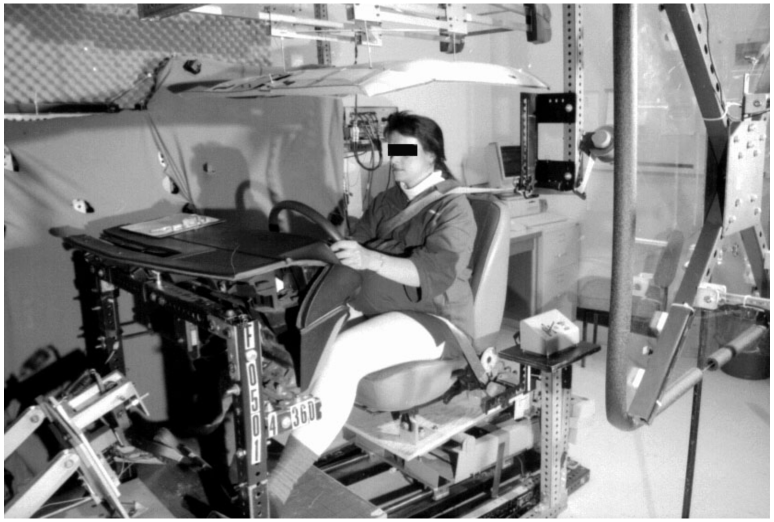
F0403 – 270-mm Seat Height



F0404 – 270-mm Seat Height

F0406 – 270-mm Seat Height

Figure I.4. Group 4 - Session 4: Subject-Selected Belt-Restraint Anchorage and Pedal Positions



F0501 – 360-mm Seat Height

F0502 – 360-mm Seat Height

F0504 – 270-mm Seat Height

F0505 – 360-mm Seat Height

Figure I.5. Group 5 - Session 4: Subject-Selected Belt-Restraint Anchorage and Pedal Positions